Sonar Estimation of Chinook and Fall Chum Salmon Passage in the Yukon River near Eagle, Alaska, 2016

by

Michael J. McDougall

and

Jody D. Lozori

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	$(F, t, \chi^2, etc.)$
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	E
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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Michael J. McDougall and Jody D. Lozori

Alaska Department of Fish and Game, Division of Commercial Fisheries, Fairbanks

Michael J. McDougall and Jody D. Lozori
Alaska Department of Fish and Game, Division of Commercial Fisheries,
1300 College Road, Fairbanks, AK 99701, USA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF APPENDICES

ABSTRACT

Adaptive resolution imaging sonar (ARIS) and split-beam sonar equipment were used to estimate Chinook salmon *Oncorhynchus tshawytscha* and fall chum salmon *O. keta* passage in the Yukon River near Eagle, Alaska, from July 1 to October 6, 2016. A total of 72,329 Chinook salmon were estimated to have passed the sonar site between July 1 and August 17. The midpoint of the Chinook salmon run occurred on July 18, which was 6 days early relative to the historical mean date. An estimated 144,035 fall chum salmon passed between August 18 and October 6. The sonar-estimated passage of fall chum salmon was subsequently expanded to a total passage estimate of 161,025 to include fish that may have passed after operations ceased. The midpoint of the expanded fall chum salmon estimate occurred on September 26, which was 4 days later than the historical mean date. Subtracting the preliminary subsistence catch upstream of the sonar site resulted in an estimated border passage of 71,574 Chinook salmon and 148,071 fall chum salmon. Drift gillnetting was conducted to collect age, sex, and length samples and tissue samples for genetic information. Species composition was also recorded to determine when the Chinook salmon run ended and the fall chum salmon run began.

Key words: Chinook salmon *Oncorhynchus* t*shawytscha,* fall chum salmon *Oncorhynchus keta*, adaptive resolution imaging sonar ARIS, dual-frequency identification sonar DIDSON, split-beam sonar, hydroacoustic, Eagle, Yukon River, Alaska

INTRODUCTION

The Yukon River is the longest river in Yukon and Alaska, spanning 3,185 km[1]. It flows northwesterly from its origin in northwestern British Columbia through the Yukon Territory and Central Alaska to its mouth at the Bering Sea. Commercial and subsistence fisheries harvest Chinook salmon *Oncorhynchus tshawytscha*, chum salmon *O. keta*, and coho salmon *O. kisutch* throughout most of the drainage. These fisheries are critical to the way of life and economy of people in dozens of communities along the river, in many instances providing the largest single source of food or income.

Fisheries management on the Yukon River is complex and difficult because of the number, diversity, and geographic range of fish stocks and user groups. Information upon which to base management decisions comes from several sources, each of which has unique strengths and weaknesses. Gillnet test fisheries provide inseason indices of run strength, but interpretation of these data are confounded by gillnet selectivity. In addition, the functional relationship between test fishery catches and abundance is poorly defined. Mark–recapture projects provide estimates of total abundance, but the information is typically not timely enough to make day-to-day management decisions. Sonar provides timely estimates of abundance, but is limited in its ability to identify fish to species level.

Alaska is obligated to manage Canadian-origin Yukon River Chinook and fall chum salmon stocks according to precautionary, abundance-based harvest-sharing principles set by the Yukon River Salmon Agreement (Yukon River Panel 2004). The goal of bilateral, coordinated management is to meet negotiated escapement goals and provide for subsistence and commercial harvests of surplus, in both the United States and Canada. Timely estimates of abundance not only help managers adjust harvest inseason, they are crucial for postseason analysis to determine whether treaty obligations were met. The Canadian Department of Fisheries and Oceans (DFO) provided estimates of mainstem salmon passage through the U.S./Canada border using mark–recapture techniques from 1980 to 2008 (JTC 2014). Because of the highly turbid water of the Yukon River, and the width of the mainstem (approximately 400 m across at the study site),

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[1]   Yukoninfo. [Internet]. Yukon River. http://www.yukoninfo.com/yukon-river/ (Accessed December 2016).

daily passage estimation methods that rely on visual observation, such as counting towers and weirs, are not feasible. Split-beam sonar technology is used successfully by the Alaska Department of Fish and Game (ADF&G) to produce daily inseason estimates of salmon passage in turbid rivers, including the lower Yukon River at Pilot Station (Lozori and McIntosh 2014). Multi-beam imagining sonar (dual-frequency identification sonar DIDSON and adaptive resolution imaging sonar ARIS[2]) have been used at several sites, including the Anvik (Lozori 2016) and the Teslin rivers (Mercer 2016), to give daily passage estimates where bottom profiles and river width are appropriate for the wider beam angle and shorter-range capabilities of this technology.

In 1992, ADF&G initiated a project near Eagle, Alaska (Figure 1), to examine the feasibility of using split-beam sonar to estimate the number of salmon migrating across the U.S./Canada border (Johnston et al. 1993; Huttunen and Skvorc 1994). This project was the first documented use of split-beam sonar in a riverine environment, and over the 3-year duration of the study, a number of problems were identified. Phase corruption was observed and was probably exacerbated by the highly reflective river bottom (Konte et al. 1996). The errors in the phase measurement were believed to have resulted in overly restrictive echo angle thresholds causing the removal of echoes from fish that were physically within accepted detection regions. These and other equipment issues reflected the early state of split-beam development, most of which have since been addressed. A recommendation of these studies was to find a more appropriate site with smaller rocks and a uniform bottom profile (Johnston et al. 1993). Too many large rocks or obstructions in the profile can compromise fish detection by limiting how close to the bottom the hydroacoustic beam can be aimed. Similarly, an uneven bottom profile permits fish to pass undetected by the sonar.

In 2003, ADF&G carried out a study to identify a more suitable location to deploy hydroacoustic equipment to estimate salmon passage into Canada. A 45 km section of river from the DFO mark–recapture fish wheel project at White Rock, Yukon Territory, to 19 km downriver from Eagle, Alaska, was explored (Pfisterer and Huttunen 2004). This area was investigated because of its proximity to the DFO project and the U.S./Canada border. Desirable characteristics included the following: consistent, downward-sloping linear bottom profiles on both sides of the river without large obstructions; a single channel; available beach above the ordinary high-water mark for topside equipment; and sufficient current (i.e., areas without eddies or slack water where fish milling behavior can occur). A total of 21 river transects led to a narrowing of potential project locations to an area between 9 km and 19 km downriver from the town of Eagle. The 2003 study identified the 2 most promising sonar deployment locations at Calico Bluff and Shade Creek. Although sonar was not deployed in 2003, the bottom profiles at the preferred sites indicated that it should be possible to estimate fish passage using a combination of split-beam sonar on the longer, linear left bank and DIDSON on the shorter, steeper right bank. ADF&G carried out a 2-week study in 2004 to test sonar at the preferred sites. The 2 types of sonar were tested at Calico Bluff and the Shade Creek area, and it was found that Six Mile Bend (11.5 km downriver from the town of Eagle and immediately upstream of Shade Creek) was the most ideal site (Carroll et al. 2007a).

In 2005, a full-scale sonar project was conducted from July 1 to August 13 to estimate Chinook salmon passage in the Yukon River at Six Mile Bend (Carroll et al. 2007b). As suggested,

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[2]   Product names used in this report are included for scientific completeness but do not constitute a product endorsement.

DIDSON was deployed on the right bank, split-beam sonar was deployed on the left bank, and this equipment has been used in subsequent years to estimate border passage for both Chinook and fall chum salmon.

The project duration was extended in 2006 to provide an estimate of chum salmon passage. However, 2 genetically distinct runs of chum salmon enter the Yukon River, an early summer component and a later fall component (Estensen et al. 2013). Summer chum salmon spawn primarily in run-off streams in the lower 700 miles of the Yukon River drainage and in the Tanana River drainage. Fall chum salmon, which migrate past the Eagle sonar project, primarily spawn in the upper portion of the drainage in streams that are spring fed or have major upwelling features. Major fall chum salmon spawning areas include the Tanana, Porcupine, and Chandalar river drainages as well as various streams in the Yukon Territory, Canada, including the mainstem Yukon River.

In 2016, the project deployed split-beam and ARIS sonar to estimate Chinook and fall chum salmon passage migrating across the U.S./Canada border. Sample fisheries were conducted to determine the transition between Chinook and fall chum salmon runs as well as collect age, sex, and length (ASL) and tissue samples for stock identification. This report will describe the methods used to collect sonar and test fishery data, provide passage estimates, species distributions, run timing, climate observations, and hydrologic observations.

OBJECTIVES

The goal of this project in 2016 was to provide daily inseason estimates of Chinook and fall chum salmon migrating across the U.S./Canada border to fishery managers. Primary objectives included the following:

1.   Begin field operations prior to the arrival of Chinook salmon, then operate continuously throughout the season until approximately October 6, when, historically, environmental conditions become unfavorable for field operations.
2.   Operate side-looking split-beam and imaging sonar such that 95% of the migrating salmon detected are within three-quarters of the ensonified range.
3.   Use drift gillnets to collect species composition and catch per unit effort (CPUE) data to estimate the transition period between the Chinook and fall chum salmon migration past the sonar site.

Secondary objectives included the following:

4.   Collect a minimum of 160 Chinook salmon scale samples during each of 3 strata throughout the season to characterize the age, sex, and length (ASL) composition of Yukon River Chinook salmon passage, such that simultaneous 95% confidence intervals of age composition are no wider than 0.20 ($\alpha = 0.05$ and $d = 0.10$). Strata dates are determined by ADF&G fishery managers based on run timing, sample size, and fish pulses.
5.   Collect a minimum of 160 fall chum salmon scale samples during each of 4 strata throughout the season to characterize the age, sex, and length (ASL) composition of Yukon River fall chum salmon passage, such that simultaneous 95% confidence intervals of age composition are no wider than 0.20 ($\alpha = 0.05$ and $d = 0.10$).
6.   Collect Chinook and fall chum salmon tissue samples for genetic stock identification.
7.   Collect daily climatic and hydrologic measurements representative of the study area.

METHODS

STUDY AREA

The study area is located on the mainstem of the Yukon River at Six Mile Bend (64°52′23.8″N, 141°04′45.12″W), approximately 11.5 km downriver from Eagle, Alaska (Figure 2). The Yukon River Basin is the fourth largest basin in North America, has a drainage area of 857,300 km^2 and an average annual discharge of 6,400 m3/s. Flows are highest in June, but the greatest flow variability occurs in May, after which discharge (and the variability in discharge) decline. The upper Yukon River is turbid and silty throughout the summer and fall, and the estimated annual suspended sediment load at Eagle is 33,000,000 tons (Brabets et al. 2000).

HYDROACOUSTIC EQUIPMENT

A fixed-location, split-beam sonar developed by Kongsberg Simrad was used to estimate salmon passage on the left bank. Fish passage was monitored with a model EK60 digital echosounder, which included a general-purpose transceiver and a 2.5° x 10° 120 kHz transducer (Table 1). ER60 data acquisition software was controlled with a Simrad Controller program (Carl Pfisterer, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication), which was installed on a laptop computer and connected to the echosounder to collect raw data for processing.

An ARIS imaging sonar, manufactured by Sound Metrics Corporation, was deployed on the right bank. The sonar was operated at 1.2 MHz (high frequency) for the nearshore stratum and at 0.70 MHz (low frequency) for the offshore stratum. Forty-eight beams were used for both strata. Both the low- and high-frequency modes have a field of view of 28° (Table 2).

Digital files created by the ER60 software and the ARIS were reviewed using the echogram viewer program Echotastic (Version 3) to produce an estimate of fish passage (Carl Pfisterer, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication).

SONAR DEPLOYMENT AND OPERATION

Each season, prior to transducer deployment, bottom profiles are checked to ensure the original sites remain acceptable for ensonification. Bottom profile data were collected from transects made from bank-to-bank using a boat-mounted Lowrance LCX-15 dual-frequency transducer (down-looking sonar) with a built-in Global Positioning System (GPS). A bottom profile was then generated using data files uploaded to a computer (Figure 3).

The split-beam transducer was attached to 2 Hydroacoustic Technology Incorporated (HTI) model 662H single-axis rotators, configured perpendicularly to provide dual-axis rotation. Aiming was performed remotely using an HTI model 660 remote control unit that provided horizontal and vertical positioning.

The split-beam sonar was deployed from July 1 through October 6 on the left bank, approximately 800 m downriver from the camp (Figure 2). The transducer and rotators were mounted on a freestanding frame constructed of aluminum pipe and deployed approximately 15 m from shore (Figure 4). Transducer height was adjusted by sliding a mounting bar up or down along riser pipes that extended above the water. The transducer was deployed at approximately 1.5 m depth and aimed perpendicular to the current, at a location with consistent flow and no slack water.

When counting Chinook salmon, the split-beam system was aimed to ensonify a range of approximately 150 m from the transducer and sampled 2 strata (S1: approximately 0–50 m and S2: approximately 50–150 m). When counting fall chum salmon, the split-beam system was aimed to ensonify a range of 75 m and sampled 2 strata (S3: approximately 0–25 m and S4: approximately 25–75 m) (Figure 5).

A portable tripod-style fish lead was constructed approximately 1.5 m downstream from the transducer to prevent fish passage inshore of the transducer and provide sufficient offshore distance for fish swimming upstream to be detected in the sonar beam. Freestanding lead sections were constructed of 2 inch diameter steel pipes connected with adjustable fittings to form tripods. Aluminum stringers, approximately 2.5 m long, were attached horizontally to the upstream side of the tripods. Vertical lengths of aluminum conduit spaced 3.8 cm apart finished the sections. Depending upon water level, flow, and debris load, lead sections were placed side-by-side in the water from shore to a distance of 5 m to 12 m beyond the transducer (Figure 6). The portability of this style of fish lead was important because of the gradual slope found on the left bank. As the water level rises and falls over the duration of the season, the transducer and lead require frequent relocation to maintain their depth in the water column.

The ARIS sonar was attached to a Sound Metrics ARIS Rotator AR2 and controlled by ARIScope software interface, which provided horizontal and vertical positioning. Aiming was performed remotely using a laptop computer.

The ARIS was deployed from July 1 through October 6 on the right bank, approximately 700 m downriver from the camp, and was aimed to ensonify approximately 40 m beginning at 0.7 m from the face of the transducer, with 2 sampling strata (S5: 0.7–20 m and S6: 20–40 m) (Figure 5). The transducer and rotator where mounted on a freestanding aluminum frame similar to the split-beam sonar (Figure 7). Operators were able to remotely adjust the aim by viewing the video image for each stratum. Proper aim was achieved when adequate bottom features appeared over a majority of the ensonified range.

A fish lead was constructed using 2 m steel "T" stakes. A lead line was strung through the bottom of the 1.2 m plastic snow fencing for weight (Figure 6). The fish lead was less than 1 m downstream from the transducer and extended 3 m offshore, beyond the transducer. This distance provided sufficient offshore diversion for fish swimming upstream to be detected in the sonar beam. A shorter lead was appropriate for this bank because of the steep slope and the shorter near field view of the ARIS.

SONAR DATA PROCESSING AND PASSAGE ESTIMATION

Operators opened each data file in an echogram viewer program (Echotastic) and marked each upstream fish track (Figures 8 and 9). The counts were saved as text files and recorded on a count form. Upstream direction of travel was verified in Echotastic using the video or by the color gradation of the track when echoes were colored by horizontal angle (Figure 8).

The daily passage ($\hat{y}$) for stratum (s) on day (d) was estimated by averaging the hourly passage rates for the hours sampled and then multiplying by the number of hours in a day as follows:

$$\hat{y}_{ds} = 24 \bullet \frac{\sum_{p-1}^{n} \frac{y_{dsp}}{h_{dsp}}}{n_{ds}}, \tag{1}$$

where h_{dsp} is the fraction of the hour sampled on day (d), stratum (s), and period (p), and y_{dsp} is the count for the same sample.

Treating the systematically sampled sonar counts as a simple random sample could yield an overestimate of the variance of the total because sonar counts can be highly autocorrelated. To accommodate these data characteristics, a variance estimator based on the squared differences of successive observations was employed (Wolter 1985). The variance for the passage estimate for stratum (s) on day (d) is estimated as:

$$\hat{V}_{y_{ds}} = 24^2 \frac{1 - f_{ds}}{n_{ds}} \frac{\sum_{p=2}^{n_{ds}} \left(\frac{y_{dsp}}{h_{dsp}} - \frac{y_{ds,p-1}}{h_{ds,p-1}} \right)^2}{2(n_{ds} - 1)}, \tag{2}$$

where n_{ds} is the number of samples in the day (typically 24), f_{ds} is the fraction of the day sampled (12/24 = 0.5 when no down time), and y_{dsp} is the hourly count for day (d) in stratum (s) for sample (p). Because the passage estimates are assumed independent between strata and among days, the total variance was estimated as the sum of the variances:

$$\hat{V}ar(\hat{y}) = \sum_{d} \sum_{s} \hat{V}ar(\hat{y}_{ds}). \tag{3}$$

MISSING DATA

Estimating daily passage by multiplying the average hourly passage rates by 24 (Equation 1) compensates for missing data (either shortened or missing periods within a day) and is reflected in the variance (Equation 2) by reducing the number of samples and the fraction of the day sampled. If 1 or multiple days were missed, daily passage was interpolated by averaging passage estimates from days before and after the missing day(s) as follows:

$$\hat{y}_d = \left(1/n \sum_{i=1}^{n} x_i \right) \begin{Bmatrix} d = 1, n = 4 \\ d = 2, n = 6 \\ d = 3, n = 8 \end{Bmatrix}, \tag{4}$$

where d is the number of missed days, n is the number of days used for interpolation (half before and half after the missing day(s)), and x_i is the passage for each day.

After editing was complete, an estimate of hourly, daily, and cumulative fish passage was produced and forwarded to the Fairbanks ADF&G office via email each day. The estimates produced during the field season were further reviewed postseason and adjusted as necessary.

Because project operations ceased prior to the end of the fall chum salmon run, the estimate was expanded using a second order polynomial equation extended to October 18, where y_i is the daily passage estimate, L is the count on the last day of sonar operation, d is the total number of days

expanding for, and x_i is the day number being estimated (where $i = 1$ through total number of days expanding for):

$$y_i = \frac{L}{d^2}(x_i - d)^2 \qquad (5)$$

October 18 was chosen based on what is considered the most likely run timing scenario derived from 1982 to 2008 historical data collected at the DFO mark–recapture fish wheel project near the U.S./Canada border (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication).

Postseason, the U.S. portion of the Chinook and fall chum salmon subsistence harvest from the Eagle area, upstream of the sonar site, was subtracted from the adjusted sonar estimate to give a border passage estimate for each species.

SPATIAL AND TEMPORAL DISTRIBUTIONS

Fish range distributions for Chinook and fall chum salmon were examined by importing text files containing all fish track information into R^3 and the fish counts were binned by range. The binned data were plotted to investigate the spatial distribution of fish passing the sonar site. Histograms of passage by hour were also created to investigate diel patterns of migration. Run timing of Chinook and fall chum salmon was examined inseason and postseason using information from the sonar estimate, fish range distribution, sample fishery catches, and local subsistence harvest.

SAMPLE FISHING

Two specific test fisheries were implemented to monitor species composition, and collect ASL and genetic samples: 1) a Chinook salmon sample fishery (July 2 to August 15) collected data to estimate specific Canadian stock proportions and the ASL composition of Chinook salmon entering Canada, and 2) a species composition fishery (August 1 to September 30) to determine the transition date between the Chinook and fall chum salmon runs, and to collect fall chum salmon ASL data.

The Chinook salmon sample fishery occurred twice daily from July 2 through August 1, from approximately 0800 to 1200 hours and again at approximately 1300 to 1700 hours. The fishery specifically targeted Chinook salmon, which are the predominant species during the months of June and July. Chinook salmon sample fishing was conducted once per day between 1300 and 1700 hours from August 1 to August 15.

Genetic and ASL samples were collected using 4 different mesh sizes (5.25-, 6.5-, 7.5-in, and 8.5-inch), which were drifted in a rotating schedule (Table 3) over the course of the Chinook salmon run to effectively capture all size classes present. Nets were 25 fathoms long, approximately 25 ft deep, and hung "even" at a 2:1 ratio of web to corkline (Table 4). Nets were drifted for approximately 6 minutes each within the left bank nearshore (LBN), left bank offshore (LBF), and right bank nearshore (RBN) zones. The right bank zone was located approximately 2.5 km upriver from the sonar site where river conditions were suitable for drift

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[3] R Development Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available for download: http://www.R-project.org.

gillnetting on that bank (Figure 2). This resulted in 9 drifts during the Chinook salmon sample fishing period.

For each drift, 4 times were recorded to the nearest second onto field data sheets: net start out (*SO*), net full out (*FO*), net start in (*SI*), and net full in (*FI*). Fishing time (*t*), in minutes, was approximated as:

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2}.$$ (6)

Total effort (*f*), in fathom-hours, of drift (*j*) and mesh size (*m*) during fishing Period l in zone (*z*) on day (*d*) was calculated as:

$$F_{dzlm} = \frac{25t_{dzlmj}}{60}.$$ (7)

Fishing for species composition and ASL collection was conducted once daily from August 1 to September 30 between approximately 0800 and 1200 hours on the left bank. During the sampling period, both 5.25- and 7.5-inch nets were drifted twice within each of the 3 left bank zones for a total of 12 drifts (Figure 2). Nets were hung the same as for the Chinook salmon sample fishery with the exception of the LBI (left bank inshore) nets, which were approximately 3 m deep (Table 4). Drifts were targeted to be 6 minutes in duration but were occasionally shortened as necessary to avoid snags or to limit catches and prevent mortalities during times of high fish passage. LBI drifts were referred to as "beach walks" (Fleischman et al. 1995) where 1 person held onto the shore end of the net and led it downstream along the beach while a boat drifted with the offshore end. The nearshore zone started approximately 1 net length from shore and the offshore zone started approximately 2 net lengths from shore. The order of drifts was 1) LBI, 2) LBN (left bank nearshore), and 3) LBF (left bank offshore), and a minimum of 15 minutes between drifts in the same zone. All drifts using 1 mesh size were completed before switching to another mesh size. Starting mesh sizes were alternated each day (Table 3).

For standard ASL samples, length was measured mid eye to tail fork (METF) to the nearest 1 mm. Sex was determined by visually examining features such as development of the kype, roundness of the belly, presence or absence of an ovipositor, and overall size. This is similar to the sampling routine used on the Kuskokwim River (Molyneaux et al. 2010). Four scales from Chinook salmon and 1 scale from fall chum salmon were removed from the preferred area of the fish on the left side approximately 2 rows above the lateral line in an area transected by a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956). All scale samples were cleaned and mounted on gum cards to be aged by ADF&G ASL lab in Anchorage.

For genetic stock identification (GSI), an axillary process was clipped from each salmon. Chinook salmon samples were stored individually in a vial of ethanol and fall chum salmon samples were stored in bulk collections of up to 200 samples. All samples were sent to ADF&G genetics laboratory and, from there, forwarded to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, British Columbia for processing. Non-salmon species were measured from nose to tail fork but were not sampled for other data. Captured fish were handled in a manner that minimized mortalities.

SPECIES DETERMINATION

Although Chinook and fall chum salmon migrations are considered discrete in time, some temporal overlap does occur. Inseason, a tentative date was chosen to represent the last day of the Chinook salmon migration, based on the daily proportions of Chinook and fall chum salmon CPUE. The remainder of the passage estimates for the season was then classified as fall chum salmon.

CPUE calculations

CPUE was calculated for each day (d) on the left bank (b) during species composition fishing using 2 specific sizes of gillnet mesh (g), regardless of catch size. Chinook salmon CPUE was calculated on the catch (c) and effort (e) (calculated in Equation 7) of the large mesh gillnet (7.5 inch); fall chum salmon CPUE was calculated on the catch and effort of the small mesh gillnet (5.25 inch). Because all nets were 25 fathoms (45.7 m) in length, CPUE estimates (in catch per fathom hour) for each species (i) were made daily for the left bank species composition test fishery.

$$CPUE_{dbi} = \frac{\sum_g c_{dbig}}{\sum_g e_{dbg}} .$$
(8)

Determination of Chinook and fall chum salmon separation date

The separation date between Chinook and fall chum salmon was determined using daily left bank CPUE values for Chinook and fall chum salmon. The daily CPUE values were smoothed using the function *supsmu* in *R* with the default span (Friedman 1984). The smoothed values were used to compute the estimated daily proportions $\hat{p}$ for the 2 species:

$$\hat{p}_{di} = \frac{CPUE_{di}}{\sum_i CPUE_{di}}$$
(9)

Because there are only 2 species, and fall chum increases while Chinook decreases, the crossover is the date at which the proportion of fall chum is greater than or equal to 0.5.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Climatic and hydrologic observations were collected at approximately 1800 hours daily. Reported stream levels are taken from the U.S. Geological Survey's gaging station at Eagle[4], although water levels were monitored at the sonar site as well. Surface water temperature was measured approximately 30 cm below the surface with a HOBO U22 water temperature data logger. Data loggers were attached to the sonar transducer stands on each bank and set to record every hour. Air temperature, wind velocity, and wind direction were measured daily using a portable weather station set up near the sonar tent site. Other daily observations included occurrence of precipitation and percent cloud cover.

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[4] USGS (U.S. Geological Survey). [Internet]. National Water Information System: Web Interface. USGS 15356000 Yukon River at Eagle Alaska. http://waterdata.usgs.gov/ak/nwis/inventory/?site_no=15356000&agency_cd=USGS&amp (Accessed: November 2016).

RESULTS

SONAR DEPLOYMENT

In 2016, both the right and left bank transducers were deployed in approximately the same locations that have been used in recent years (Figure 2). The left bank profile was linear, extending approximately 300 m to the thalweg at a 2.9° slope. The right bank profile was less linear, shorter, and steeper, extending approximately 100 m to the thalweg at a 9.1° slope (Figure 3). The substrate at Six Mile Bend was large cobble to small boulder on the right bank and small to medium sized cobble and silt on the left bank.

CHINOOK AND FALL CHUM SALMON PASSAGE ESTIMATION

Inseason, August 17 was determined to be the last day of the Chinook salmon run based on relatively low sonar counts and catches from the species composition test fishery (Figure 10). Postseason analysis of CPUE data for both the large and small mesh nets (7.50 inch and 5.25 inch) from the species composition test fishery were plotted by day, and the relationship between the variables summarized using the Friedman's supersmoother algorithm (Figure 11; Appendix A1). The plot also suggested the last day of the Chinook salmon run was August 17.

The total passage estimate at the Eagle sonar site for Chinook salmon was 72,329 from July 1 through August 17. The first quarter point was on July 14, the midpoint on July 18, and three-quarter point on July 25 (Table 5). Peak daily passage estimate of 4,388 Chinook salmon occurred on July 14 and 101 fish passed on August 17, which was the last day of the Chinook salmon season (Figure 12). Compared to historical mean run timing from 2005 to 2015, the midpoint of the Chinook salmon run occurred 6 days early (Figure 13)[5]. Sampling time missed during this period varied by stratum, and totals ranged from 8.8 hours to 39.0 hours (Table 6). Time missed was generally due to wireless connection failures, as well as down time while adjusting weir panels and re-aiming or cleaning the sonars. There were no full days of sampling missed this season.

The preliminary subsistence harvest from the Eagle area upstream of the sonar was 755 Chinook salmon (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication). Postseason, adjustment for subsistence Chinook salmon harvest produced a border passage estimate of 71,574 Chinook salmon (Table 7). This estimate was above the upper end of the preseason projection[6] and the interim management escapement goal (IMEG)[7] of 42,500 to 55,000 fish.

The total fall chum salmon sonar passage estimate was 144,035 fish from August 18 through October 6. Approximately 3.4% (4,835 fish) of the total fall chum salmon passage occurred on October 6, the last day of operation (Table 8). Because fall chum salmon passage continued after

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[5] Differences in the transition dates for species crossover confounds computation of the historical daily cumulative and mean. As a convenience, the historical daily cumulative percent and mean were computed by assuming that 100% of the run was completed on the date the Chinook salmon run transitioned to fall chum salmon.

[6] Carroll, H., and S. Garcia. [Internet]. 2016 Preliminary Yukon River summer season summary, Alaska Department of Fish and Game, Division of Commercial Fisheries, News Release, Juneau Alaska. [Issued: 2016 October 5; Cited: December 12, 2016] Available from: http://www.adfg.alaska.gov/static/applications/dcfnewsrelease/749060246.pdf.

[7] The U.S./Canada Yukon River Panel agreed to a 1 year Canadian interim management escapement goal (IMEG) of 42,500–55,000 Chinook salmon based on the Eagle sonar program. In order to meet this goal, the passage at Eagle sonar must include a minimum of 42,500 fish for escapement, provide for a subsistence harvest in the community of Eagle upstream of the sonar (approximately 1,000–2,000 fish), and incorporate Canadian harvest sharing as dictated in the U.S./Canada Yukon River Treaty (20%–26% of the total allowable catch).

the project was terminated, the sonar estimate was expanded, and adjusted to 161,025 fish (Figure 12). The first quarter point of the run fell on September 18, the midpoint on September 26, and three-quarter point on October 2. These quartiles were calculated using the expanded passage estimate after the sonar project was terminated (Table 8). Fall chum salmon passage peaked on September 30 and the daily estimate was 7,583 fish (Figure 12). Compared to historical mean run timing from 2006 through 2015, the midpoint of the fall chum salmon run occurred 4 days later than the historic mean date (Figure 13). Sampling time missed during the fall chum migration varied by stratum, and totals ranged from 8.8 hours to 74.4 hours (Table 9).

The preliminary fall chum salmon subsistence harvest from the Eagle area was 12,954 fish (Bonnie Borba, Commercial Fisheries Biologist, ADF&G, Fairbanks; personal communication). Postseason, adjusting for subsistence harvest produced a border passage estimate of 148,071 fish (Table 7). After accounting for preliminary Canadian harvest from both the First Nation (1,000) and Canadian Commercial/Domestic (1,745) fisheries[8], total fall chum salmon escapement was estimated to be 145,326 fish[9] for the mainstem Yukon River in Canada. This exceeded the IMEG range of 70,000–104,000 fish[10] and provided for harvest under the sharing agreement.

The objectives of operating continuously throughout the season until approximately October 6, as well as operating side-looking split-beam and imaging sonar such that 95% of the migrating salmon are detected within three-quarters of the ensonified range, were achieved

SPATIAL AND TEMPORAL DISTRIBUTION

Fish were shore oriented on both banks (Figures 14 and 15). On the left bank, during the Chinook salmon migration, approximately 96% of the fish were detected within 60 m of the transducer and 99% within 80 m. On the right bank, 96% of the fish were detected within 20 m of the transducer and 99% within 25 m.

During the fall chum salmon migration, approximately 98% of the fish were detected within 20 m of the transducer and 99% within 25 m on the left bank. On the right bank, approximately 98% of the fish were detected within 6 m of the transducer and 99% within 8 m. Approximately 80% of Chinook salmon and 68% of fall chum salmon passed on the left bank.

Although overall Chinook salmon migration (both banks combined) past the sonar does not suggest a distinct diel migration pattern, a slight decrease in passage on the left bank and an increase on the right bank was evident between 0800 and 1600 (Figure 16). This period corresponds with the test fishery schedule and suggests there may be a relationship between the fishing schedule and daily Chinook salmon passage. Because the right-bank test fishery occurred far upstream from the sonar (Figure 2), effectively only the left-bank salmon passage was affected.

Similarly, but more distinctive, the fall chum salmon passage increased on the right bank during the morning test fishery (Figure 17). It is noteworthy to mention that test fishing is not conducted on the right bank during the majority of the fall chum salmon migration.

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[8] Canadian Yukon River Salmon 2016 postseason review Mainstem and Porcupine Chum Salmon: Yukon River Panel, December 10-14, 2016, Anchorage, Alaska; Power Point presentation.

[9] Estimated mainstem Yukon River Canadian escapement is derived from Eagle sonar estimate (expanded through October 18; 2008 to present) minus harvest from Eagle community upstream including Canadian harvests.

[10] Estensen, J., and B. Borba. 2016. 2016 Yukon River Fall Season Summary. Alaska Department of Fish and Game, Division of Commercial Fisheries, News Release, Fairbanks Alaska. [Issued: December 6, 2016] Available from: http://www.adfg.alaska.gov/static/applications/dcfnewsrelease/757587459.pdf (Accessed: December 2016).

SAMPLE FISHING

A total of 766 Chinook and 941 fall chum salmon were captured in drift gillnets between July 2 and September 30 (Table 10). Fishing for species composition and sample collection occurred from August 1 to September 30, and additional Chinook salmon sample fishing occurred from July 2 to August 15. Seven sheefish *Stenodus leucichthys*, 1 arctic grayling *Thymallus arcticus*, 1 humpback whitefish *Coregonus pidschian*, 3 burbot *Lota lota*, and 2 longnose sucker *Catostomus catostomus* were captured. The number of Chinook and fall chum salmon captured in drift gillnets by sampling purpose (species composition sampling or Chinook salmon sampling) is summarized in Tables 11 and 12.

The cumulative Chinook salmon CPUE was similar to the CPUE observed in 2014, and the fall chum salmon cumulative CPUE was the highest historically observed, slightly exceeding 2013 (Figure 18). There was 1 known Chinook and no known fall chum salmon capture mortalities. Six Chinook salmon had clipped adipose fins, indicating they held coded wire tags from the hatchery in Whitehorse, Yukon Territory. These fish were retained and the heads sent to the ADF&G Mark, Tag, and Age Lab in Juneau, Alaska.

Chinook salmon samples collected from driftnets were composed of 498 (67%) males and 250 females. Fall chum salmon samples from driftnets were composed of 589 (68%) males and 273 females. ASL samples from all Chinook and fall chum salmon (unless recaptured) were collected and sent to the ADF&G age determination laboratory in Anchorage for processing. Genetic samples from Chinook and fall chum salmon were collected and sent to the ADF&G Genetics Laboratory in Anchorage, Alaska, and, from there, forwarded to the Fisheries and Oceans Canada genetics laboratory in Nanaimo, British Columbia, for processing.

The objective to collect a minimum of 160 Chinook salmon ASL samples was met in 2 of the 3 strata, and the objective to collect 160 fall chum salmon ASL samples was met in 3 of the 4 strata (Table 13). Goals to collect Chinook and fall chum tissue samples for genetic stock identification were achieved.

CLIMATE AND HYDROLOGIC OBSERVATIONS

Weather and water observations were recorded at the sonar site daily (Appendix B). Water temperature on the left bank decreased over the course of the season; the maximum observed was 19.0ºC on July 12–13, and the minimum was 2.0°C on October 5 (Figure 19). The water level was below the historic median (1995–2015) on July 1 when sonar operations began. Water levels remained at or below the median until July 16, when an increase began after which it remained above the median until September 4. From this point on it remained near the historical median for the rest of the season. The water level exceeded the historical maximum on August 13 and remained near the maximum for a brief time until August 17 (Figure 20). All goals to collect climatic and hydrologic measurements were achieved this season.

DISCUSSION

Overall there were no significant problems with project operations and both sonars performed well the entire season. Occasionally, rapid water level fluctuations and substantial debris did make it necessary to frequently move the transducers and fish leads to deeper or shallower water; however, this is not uncommon and did not affect sonar operation.

During the last week of operations, freezing temperatures occasionally caused the right bank generator carburetor to ice up and stop running. This required changing generators and restarting the equipment. Additionally, the ARIS command module would stop functioning when subjected to these temperatures, resulting in an error code warning that the module was too hot. The problem was resolved by installing a 100 watt lightbulb inside the box housing the right bank sonar equipment.

Early in the season, we experimented using an EFOY fuel cell and a 150 watt solar array to power the right bank sonar equipment, similar to the fuel cell configuration used at the Peterson Creek DIDSON assessment project (Coyle and Reed 2012). Although this system worked well without out any power outages, there are no Alaska distributors, and the cost of EFOY methanol cartridges shipped to Fairbanks was cost prohibitive. It may, however, be useful to use the EFOY system during the last month of the season to prevent down time caused by cold temperatures, because the system is useable year round, including during subzero temperatures.[11]

ACKNOWLEDGMENTS

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[11] EFOY Energy For You. [Internet]. Efoy fuel cells-off-grid power supplies full batteries. http://www.efoy.com/ (Accessed December 2016).

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TABLES AND FIGURES

Table 1.–Split-beam sonar system settings at the Eagle sonar site on the Yukon River 2016.

Component	Setting	Stratum [a]	Value
Transducer	Beam size (h x w)	All	2.5° x 10.0°
Echosounder	Power output (W)	All	500
	Pulse width (μ)	All	256
	Ping rate (pps)	S1	8.33
		S2	4.16
		S3	16.66
		S4	8.33
	Range (m)	S1	50
		S2	150
		S3	25
		S4	75
	Duration (min)	S1	30
		S2	30
		S3	30
		S4	30

[a] When counting Chinook salmon, the split-beam system was aimed to ensonify a range of approximately 150 m from the transducer, and sampled 2 strata (S1: approximately 0–50 m, and S2: approximately 50–150 m). When counting fall chum salmon, the split-beam system was aimed to ensonify 2 strata (S3: approximately 0–25, and S4: approximately 25–75 m).

Table 2.–Technical specifications and settings for the adaptive resolution imaging sonar (ARIS) at the Eagle sonar site on the Yukon River, 2016.

Setting	Stratum[a]	Value
Mode	S5	Identification
	S6	Detection
Frequency (MHz)	S5	1.20
	S6	0.70
Number of beams	S5	48
	S6	48
Start range (m)	S5	0.7
	S6	20.7
End range (m)	S5	20.7
	S6	40.0
Frame rate	S5	6 frames/s
	S6	4 frames/s
Duration in minutes	S5, S6	30
Field of view	S5, S6	28°

[a] The 2 ARIS sampling strata (S5: 0.7–20 m and S6: 20–40 m) were independently aimed using a Sound Metrics AR2 Rotator and ARIScope software.

Table 3.–Net schedule of mesh sizes (inches) for species composition and additional Chinook salmon samples, all zones, at the Eagle sonar project on the Yukon River, 2016.

Sampling purpose	Day	Net order		
		1	2	3
Species composition	1	5.25	7.50	NA
	2	7.50	5.25	NA
Additional Chinook salmon samples	1	5.25	6.50	7.50
	2	7.50	8.50	6.50
	3	6.50	5.25	8.50
	4	8.50	7.50	5.25

Table 4.–Specifications for drift gillnets used for test fishing at the Eagle sonar project on the Yukon River, 2016.

Method	Stretch mesh size		Mesh diameter	Meshes deep	Depth
	(inch)	(mm)	(mm)	(MD)	(m)
Drift	5.25	133	85	69	8.00
	6.50	165	105	55	7.90
	7.50	191	121	48	8.00
	8.50	216	137	43	8.10
Beach walk	5.25	133	85	26	3.00
	7.50	191	121	18	3.00

Note: Gillnet webbing consisted of Momoi MTC or MT, shade 11 or equivalent, double knot multifilament nylon twine.

Table 5.–Estimated daily and cumulative Chinook salmon passage by bank at the Eagle sonar project on the Yukon River, 2016.

Date	Daily			Cumulative			
	Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
07/01 [a]	182	118	300	182	118	300	0.004
07/02	278	106	384	460	224	684	0.009
07/03	306	168	474	766	392	1,158	0.016
07/04	388	203	591	1,154	595	1,749	0.024
07/05	386	229	615	1,540	824	2,364	0.033
07/06	386	267	653	1,926	1,091	3,017	0.042
07/07	466	428	894	2,392	1,519	3,911	0.054
07/08	650	544	1,194	3,042	2,063	5,105	0.071
07/09	630	771	1,401	3,672	2,834	6,506	0.090
07/10	1,050	742	1,792	4,722	3,576	8,298	0.115
07/11	1,204	1,019	2,223	5,926	4,595	10,521	0.145
07/12	2,018	942	2,960	7,944	5,537	13,481	0.186
07/13	2,306	1,421	3,727	10,250	6,958	17,208	0.238
07/14	3,144	1,244	4,388	13,394	8,202	21,596	0.299
07/15	2,902	1,090	3,992	16,296	9,292	25,588	0.354
07/16	3,630	232	3,862	19,926	9,524	29,450	0.407
07/17	3,196	292	3,488	23,122	9,816	32,938	0.455
07/18	2,928	339	3,267	26,050	10,155	36,205	0.501
07/19	2,718	424	3,142	28,768	10,579	39,347	0.544
07/20	2,764	290	3,054	31,532	10,869	42,401	0.586
07/21	2,848	127	2,975	34,380	10,996	45,376	0.627
07/22	3,172	92	3,264	37,552	11,088	48,640	0.672
07/23	2,614	161	2,775	40,166	11,249	51,415	0.711
07/24	2,354	265	2,619	42,520	11,514	54,034	0.747
07/25	2,267	241	2,508	44,787	11,755	56,542	0.782
07/26	1,932	200	2,132	46,719	11,955	58,674	0.811
07/27	1,732	286	2,018	48,451	12,241	60,692	0.839
07/28	1,412	266	1,678	49,863	12,507	62,370	0.862
07/29	1,090	266	1,356	50,953	12,773	63,726	0.881
07/30	1,014	170	1,184	51,967	12,943	64,910	0.897
07/31	785	66	851	52,752	13,009	65,761	0.909
08/01	620	46	666	53,372	13,055	66,427	0.918
08/02	756	76	832	54,128	13,131	67,259	0.930
08/03	660	91	751	54,788	13,222	68,010	0.940
08/04	624	88	712	55,412	13,310	68,722	0.950
08/05	518	72	590	55,930	13,382	69,312	0.958
08/06	371	60	431	56,301	13,442	69,743	0.964

-continued-

Table 5.–Page 2 of 2.

Date	Daily			Cumulative			
	Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
08/07	380	83	463	56,681	13,525	70,206	0.971
08/08	374	56	430	57,055	13,581	70,636	0.977
08/09	298	70	368	57,353	13,651	71,004	0.982
08/10	268	21	289	57,621	13,672	71,293	0.986
08/11	196	10	206	57,817	13,682	71,499	0.989
08/12	82	20	102	57,899	13,702	71,601	0.990
08/13	118	35	153	58,017	13,737	71,754	0.992
08/14	150	26	176	58,167	13,763	71,930	0.994
08/15	110	30	140	58,277	13,793	72,070	0.996
08/16	142	16	158	58,419	13,809	72,228	0.999
08/17 [b]	70	31	101	58,489	13,840	72,329	1.000
Var				123,762	29,121	152,883	
SE				352	171	391	

Note: The outside box identifies the second and third quartile of run, the inside box identifies median day of passage.

[a] Sonar operational on both banks.

[b] Last day of Chinook salmon estimation.

Table 6.–Sampling time, in minutes, missed by bank, zone, and date during Chinook salmon sampling at the Eagle sonar project on the Yukon River, 2016.

	Left bank		Right bank	
Date	0–50 m	50–150 m	0–20 m	20–40 m
07/01	336	336	462	420
07/02	0	0	0	6
07/03	0	0	0	0
07/04	0	0	0	6
07/05	0	0	48	30
07/06	0	0	6	12
07/07	0	0	0	0
07/08	0	0	0	0
07/09	0	0	0	30
07/10	0	0	0	0
07/11	0	0	12	12
07/12	0	0	0	0
07/13	60	60	12	0
07/14	0	0	0	0
07/15	0	0	0	0
07/16	0	0	0	0
07/17	0	0	18	30
07/18	0	0	48	24
07/19	0	0	48	30
07/20	0	0	12	0
07/21	0	0	108	90
07/22	0	0	162	132
07/23	0	0	36	30
07/24	0	0	120	36
07/25	30	30	102	0
07/26	0	0	186	156
07/27	0	0	30	0
07/28	0	0	48	30
07/29	0	0	78	12
07/30	0	0	48	30
07/31	30	12	102	72
08/01	0	0	42	0
08/02	0	0	18	12
08/03	0	0	0	30
08/04	0	0	0	0
08/05	0	0	0	0
08/06	60	30	0	0
08/07	0	0	12	60
08/08	0	0	30	12
08/09	0	0	18	6
08/10	0	0	66	36
08/11	0	0	180	108
08/12	0	0	18	0
08/13	0	0	90	162
08/14	0	0	12	6
08/15	0	0	12	0
08/16	12	6	0	0
08/17	0	0	156	36
Total min	528	474	2,340	1,656
Total hours	8.8	7.9	39.0	27.6

23

Table 7.–Eagle sonar estimate, Eagle area subsistence harvest, and border passage estimates, 2005–2016.

Date	Sonar estimate			Subsistence harvest				Border passage estimate		
	Chinook	Fall chum		Chinook		Fall chum		Chinook	Fall chum
2005	81,528	ND		2,566		ND		78,962	ND
2006	73,691	236,386		2,303		17,775		71,388	218,611
2007	41,697	265,008 [a]		1,999		18,691		39,698	246,317
2008	38,097	185,409 [a]		815		11,381		37,282	174,028
2009	69,957	101,734 [a]		382		6,995		69,575	94,739
2010	35,074	133,413 [a]		604		11,432		34,470	121,498
2011	51,271	224,355 [a]		370		12,477		50,901	211,878
2012	34,747	153,248 [a]		91		11,681		34,656	141,567
2013	30,725	216,794 [a]		152 [b]		12,692 [b]		30,573	204,102
2014	63,482	172,887 [a]		55 [b]		13,575 [b]		63,427	159,312
2015	84,015	125,095 [a]		341 [b]		12,540 [b]		83,674	112,555
2016	72,329	161,025 [a]		755 [b]		12,954 [b]		71,574	148,071

Note: ND indicates that data were not collected. Estimates for subsistence caught salmon between the sonar site and border (Eagle area) prior to 2008 include an unknown portion caught below the sonar site. This number is probably in the hundreds for Chinook salmon, and a few thousand for fall chum salmon. Starting in 2008, the estimates for subsistence caught salmon only include salmon harvested between the sonar site and the U.S./Canada border.

[a] Expanded sonar estimate includes expansion for fish that may have passed after sonar operations ceased.

[b] Subsistence estimates are preliminary.

Table 8.–Estimated daily and cumulative fall chum salmon passage by bank at the Eagle sonar project, on the Yukon River, 2016.

	Daily			Cumulative			
Date	Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
08/18 [a]	64	16	80	64	16	80	0.000
08/19	107	24	131	171	40	211	0.001
08/20	108	36	144	279	76	355	0.002
08/21	136	39	175	415	115	530	0.003
08/22	202	62	264	617	177	794	0.005
08/23	338	42	380	955	219	1,174	0.007
08/24	500	83	583	1,455	302	1,757	0.011
08/25	630	91	721	2,085	393	2,478	0.015
08/26	874	141	1,015	2,959	534	3,493	0.022
08/27	1,118	193	1,311	4,077	727	4,804	0.030
08/28	1,372	148	1,520	5,449	875	6,324	0.039
08/29	1,392	77	1,469	6,841	952	7,793	0.048
08/30	1,654	64	1,718	8,495	1,016	9,511	0.059
08/31	1,578	42	1,620	10,073	1,058	11,131	0.069
09/01	1,508	85	1,593	11,581	1,143	12,724	0.079
09/02	1,604	131	1,735	13,185	1,274	14,459	0.090
09/03	1,686	88	1,774	14,871	1,362	16,233	0.101
09/04	1,618	128	1,746	16,489	1,490	17,979	0.112
09/05	1,532	137	1,669	18,021	1,627	19,648	0.122
09/06	1,446	156	1,602	19,467	1,783	21,250	0.132
09/07	1,512	189	1,701	20,979	1,972	22,951	0.143
09/08	1,420	234	1,654	22,399	2,206	24,605	0.153
09/09	1,532	290	1,822	23,931	2,496	26,427	0.164
09/10	1,274	287	1,561	25,205	2,783	27,988	0.174
09/11	1,358	404	1,762	26,563	3,187	29,750	0.185
09/12	1,243	486	1,729	27,806	3,673	31,479	0.195
09/13	1,312	490	1,802	29,118	4,163	33,281	0.207
09/14	1,287	531	1,818	30,405	4,694	35,099	0.218
09/15	1,106	311	1,417	31,511	5,005	36,516	0.227
09/16	1,192	318	1,510	32,703	5,323	38,026	0.236
09/17	1,352	339	1,691	34,055	5,662	39,717	0.247
09/18	1,648	260	1,908	35,703	5,922	41,625	0.259
09/19	1,920	227	2,147	37,623	6,149	43,772	0.272
09/20	2,626	710	3,336	40,249	6,859	47,108	0.293
09/21	3,214	656	3,870	43,463	7,515	50,978	0.317
09/22	4,029	1,093	5,122	47,492	8,608	56,100	0.348
09/23	4,034	1,788	5,822	51,526	10,396	61,922	0.385
09/24	5,008	1,918	6,926	56,534	12,314	68,848	0.428
09/25	4,600	2,361	6,961	61,134	14,675	75,809	0.471
09/26	4,698	2,356	7,054	65,832	17,031	82,863	0.515
09/27	4,688	2,890	7,578	70,520	19,921	90,441	0.562
09/28	4,623	2,428	7,051	75,143	22,349	97,492	0.605

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Table 8.–Page 2 of 2.

Date		Daily			Cumulative			
		Left bank	Right bank	Total	Left bank	Right bank	Total	Proportion of total passage
09/29		3,890	2,752	6,642	79,033	25,101	104,134	0.647
09/30		4,144	3,439	7,583	83,177	28,540	111,717	0.694
10/01		3,964	3,276	7,240	87,141	31,816	118,957	0.739
10/02		2,960	3,057	6,017	90,101	34,873	124,974	0.776
10/03		2,752	1,817	4,569	92,853	36,690	129,543	0.804
10/04		2,490	2,558	5,048	95,343	39,248	134,591	0.836
10/05		2,616	1,993	4,609	97,959	41,241	139,200	0.864
10/06	[b]	2,616	2,219	4,835	100,575	43,460	144,035	0.894
10/07	[c]	2,198	1,865	4,063	102,773	45,325	148,098	0.920
10/08	[c]	1,817	1,541	3,358	104,590	46,866	151,455	0.941
10/09	[c]	1,472	1,248	2,720	106,061	48,114	154,175	0.957
10/10	[c]	1,163	986	2,149	107,224	49,100	156,324	0.971
10/11	[c]	890	755	1,645	108,114	49,855	157,969	0.981
10/12	[c]	654	555	1,209	108,768	50,410	159,178	0.989
10/13	[c]	454	385	839	109,222	50,795	160,017	0.994
10/14	[c]	291	247	537	109,513	51,042	160,555	0.997
10/15	[c]	164	139	302	109,677	51,180	160,857	0.999
10/16	[c]	73	62	134	109,749	51,242	160,991	1.000
10/17	[c]	18	15	34	109,767	51,257	161,025	1.000
10/18	[c]	0	0	0	109,767	51,257	161,025	1.000
Var	[d]				213,794			
SE	[d]							

Note: Median is based on inseason sonar estimates and does not include postseason expansion. The outside box identifies the second and third quartile of run, including the expanded estimate. The inside box identifies median day of passage, including the expanded estimate.

[a] First day of fall chum salmon counts.

[b] Last day of sonar operation.

[c] Expanded passage estimate.

[d] Variance and standard error are only calculated to October 6, which was the last day of sonar operation.

Table 9.–Sampling time, in minutes, missed by bank, zone, and date during fall chum salmon sampling at the Eagle sonar project on the Yukon River, 2016.

	Left bank		Right bank	
Date	0–25m	25–75m	0–20 m	20–40 m
08/18	0	0	0	0
08/19	60	30	84	30
08/20	0	0	6	12
08/21	0	0	24	36
08/22	0	0	6	12
08/23	0	0	6	0
08/24	18	30	84	36
08/25	0	0	378	294
08/26	0	0	168	150
08/27	0	0	0	6
08/28	0	0	0	0
08/29	0	0	36	18
08/30	0	0	186	120
08/31	30	30	114	66
09/01	0	0	30	6
09/02	0	0	336	186
09/03	0	0	66	30
09/04	0	0	0	12
09/05	0	0	6	12
09/06	0	0	48	30
09/07	0	0	30	6
09/08	0	0	30	0
09/09	0	0	12	0
09/10	0	0	120	78
09/11	0	0	12	0
09/12	30	30	30	0
09/13	0	0	30	30
09/14	0	0	108	156
09/15	0	0	30	0
09/16	0	0	30	30
09/17	0	0	180	222
09/18	0	0	222	282
09/19	0	0	30	12
09/20	0	0	0	0
09/21	0	0	6	0
09/22	30	0	234	138
09/23	0	0	336	228
09/24	30	6	30	6
09/25	0	0	54	66
09/26	0	0	0	18
09/27	0	0	0	0

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Table 9.–Page 2 of 2.

Date	Left bank		Right bank	
	0–25m	25–75m	0–20 m	20–40 m
09/28	0	30	0	18
09/29	0	0	0	0
09/30	0	0	30	36
10/01	0	0	0	0
10/02	12	12	12	0
10/03	0	0	198	186
10/04	0	0	372	342
10/05	0	0	234	270
10/06	360	360	516	570
Total min	570	528	4,464	3,750
Total hours	9.5	8.8	74.4	62.5

Table 10.–Fish caught with gillnets at the Eagle sonar project, on the Yukon River, 2016.

Species	Species composition	Chinook sampling	Total [a]
Chinook salmon	81	685	766
Fall chum salmon	941	0	941
Sheefish	7	0	7
Whitefish	1	0	1
Burbot	3	0	3
Grayling	1	0	1
Sucker	2	0	2
Total	1,036	685	1,721

[a] Totals include any recaptures.

Table 11.–Species composition fishing effort, catch, and percentage by zone and mesh for Chinook and fall chum salmon, at the Eagle sonar project, on the Yukon River 2016.

Zone[a]	Mesh size (inches)	Effort (fathom hours)	Chinook salmon Catch	Chinook salmon Proportion		Fall chum salmon Catch	Fall chum salmon Proportion
LBI	5.25	358.0	8	0.10		584	0.62
	7.50	346.4	16	0.20		206	0.22
Total		704.4	24	0.30		790	0.84
LBN	5.25	342.7	18	0.22		95	0.10
	7.50	340.4	36	0.44		53	0.06
Total		683.1	54	0.67		148	0.16
LBF	5.25	291.3	1	0.01		2	0.00
	7.50	295.1	2	0.02		1	0.00
Total		586.4	3	0.04		3	0.00
	Grand total	1,973.9	81	1.00		941	1.00

[a] Gillnets were drifted through 3 zones on the left bank: left bank inshore (LBI), which was held from shore and led downstream while a boat drifted with the offshore end; left bank nearshore (LBN), which was drifted approximately 1 net length from shore; and left bank offshore (LBF), which was drifted approximately 2 net lengths from shore.

Table 12.–Chinook salmon sample fishing effort, catch, and percentage for Chinook and fall chum salmon, Eagle sonar project, on the Yukon River 2016.

Zone[a]	Mesh size (inches)	Effort (fathom hours)	Chinook salmon		Fall chum salmon	
			Catch	Proportion	Catch	Proportion
LBN	5.25	157.6	164	0.24	0	0.00
	6.50	158.1	160	0.23	0	0.00
	7.50	166.5	142	0.21	0	0.00
	8.50	147.0	90	0.13	0	0.00
Total		629.2	556	0.81	0	0.00
RBN	5.25	149.8	21	0.03	0	0.00
	6.50	146.9	24	0.04	0	0.00
	7.50	148.2	15	0.02	0	0.00
	8.50	144.5	15	0.02	0	0.00
Total		589.4	75	0.11	0	0.00
LBF	5.25	153.5	9	0.01	0	0.00
	6.50	144.0	19	0.03	0	0.00
	7.50	146.3	14	0.02	0	0.00
	8.50	141.3	12	0.02	0	0.00
Total		585.1	54	0.08	0	0.00
Grand total		1,803.7	685	1.00	0	0.00

[a] Gillnets were drifted through 3 zones: left bank nearshore (LBN), which was drifted approximately 1 net length from shore; left bank offshore (LBF), which was drifted approximately 2 net lengths from shore; and right bank nearshore (RBN), which was drifted approximately 1 net length from shore.

Table 13.–Number of salmon scales sampled at the ADF&G age determination laboratory, by stratum dates, to characterize age, sex, and length (ASL) composition at the Eagle sonar project, on the Yukon River 2016.

Stratum dates [a]	Chinook salmon	Fall chum salmon
07/02–07/17	327	NA
07/18–08/02	343	NA
08/03–08/17	78	NA
08/18–08/28	NA	50
08/29–09/08	NA	201
09/09–09/19	NA	167
09/20–09/30[b]	NA	440
Total	748	862

Note: NA indicates that data is not applicable.

[a] Stratum dates are based on the species crossover date (August 17). This table does not represent total catch or samples by species.

[b] Last day of sample fishing
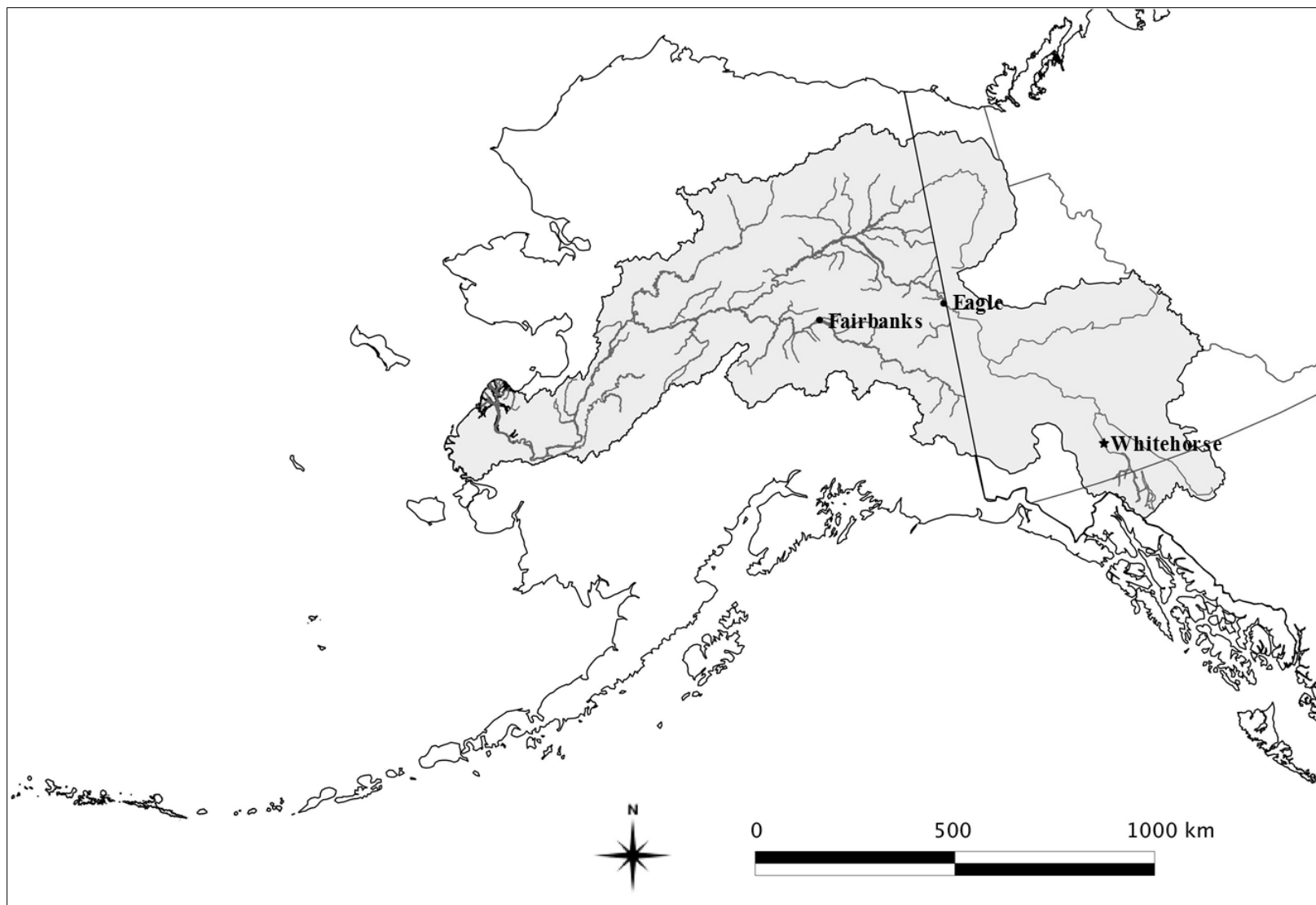
Figure 1.–Yukon River drainage.
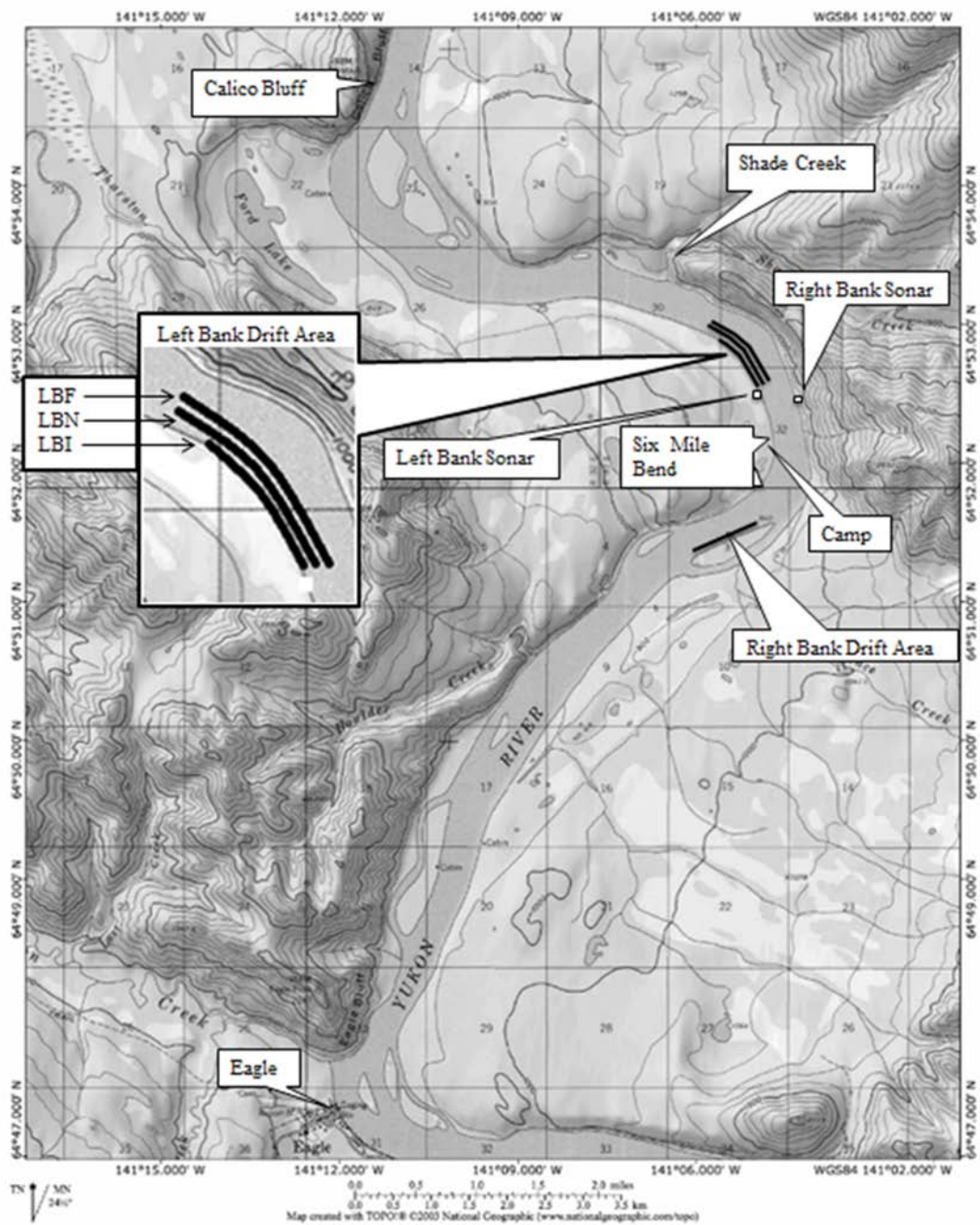
Figure 2.–Eagle sonar project site at Six Mile Bend on the Yukon River, showing sonar and drift gillnet fishing locations, 2016.
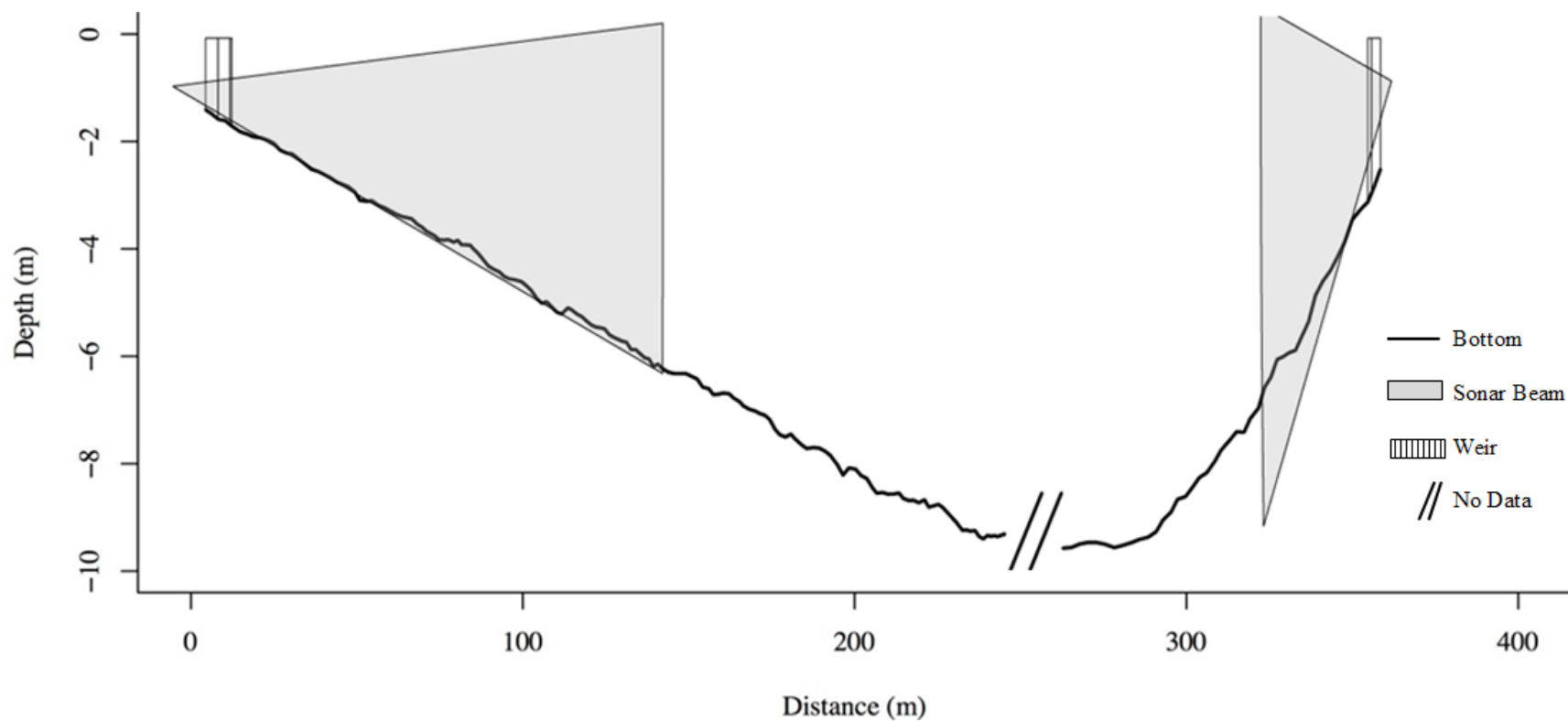
Figure 3.–Depth profile of Yukon River in front of transducers (downstream view), and approximate sonar coverage at the Eagle sonar project.

Note: To avoid damage to the outboard motor and transducer, bathymetric data collection began offshore at a depth of approximately 2 m.

Figure 4.–Split-beam transducer mounted to an aluminum H-mount (top) and the same transducer mounted to 2 single-axis automated rotators (bottom), used on the left bank at the Eagle sonar project, on the Yukon River, 2016.

Left bank split-beam

Right bank ARIS

↑ ↑ ↑
Downstream

← Sonar Beam →

Stratum 1   Stratum 2

Stratum 3   Stratum 4

Stratum 6   Stratum 5

0   25   50   75   100   125   150

40   20   0

Distance offshore (m)

Distance offshore (m)
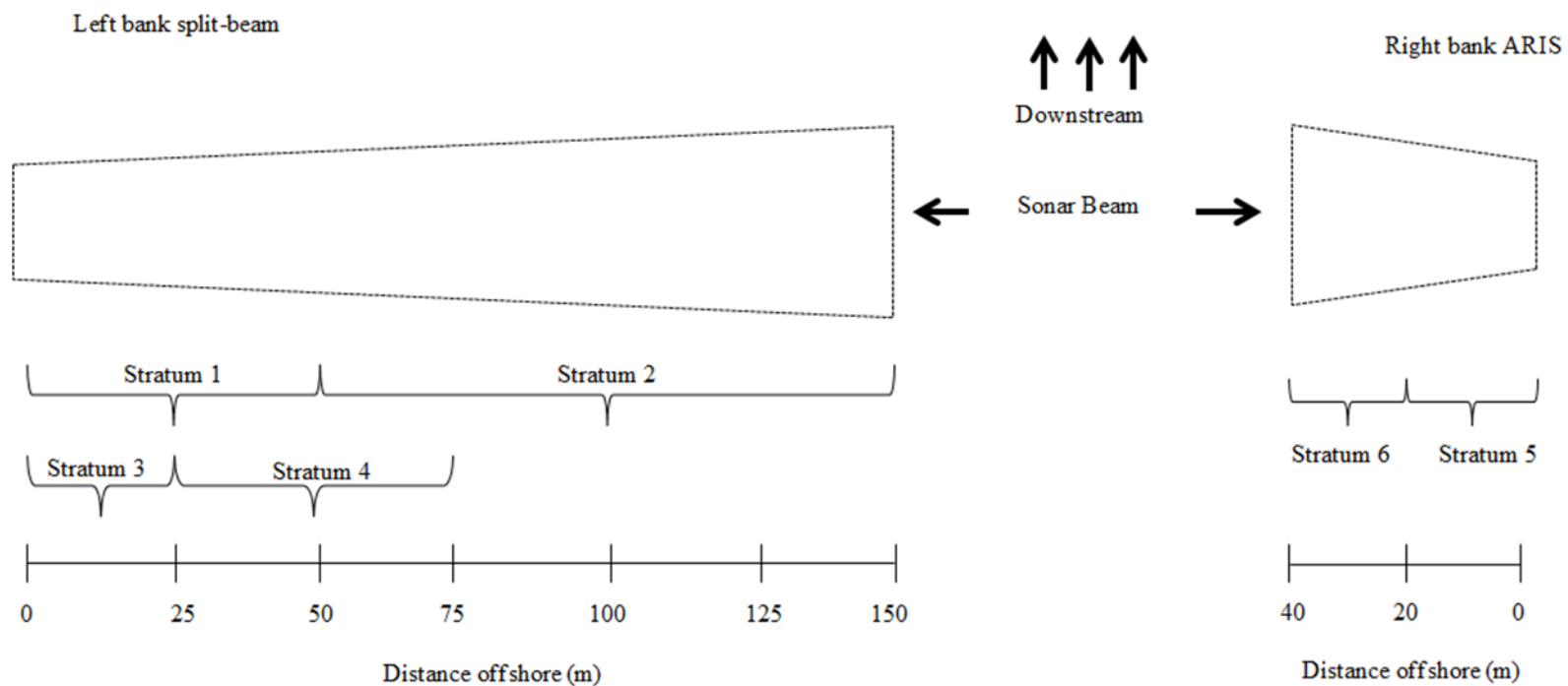
Figure 5.–Illustration of strata and approximate sonar ranges (not to scale) at the Eagle sonar project, on the Yukon River 2016.

Figure 6.–Portable tripod-style fish lead used on the left bank (top) and plastic snow fencing used on the right bank at the Eagle sonar project, on the Yukon River, 2016.

Figure 7.–View of ARIS imaging sonar and AR2 rotator mounted to an aluminum H mount (top), and close-up view of mount for rotator (bottom), at the Eagle sonar project on the Yukon River, 2016.
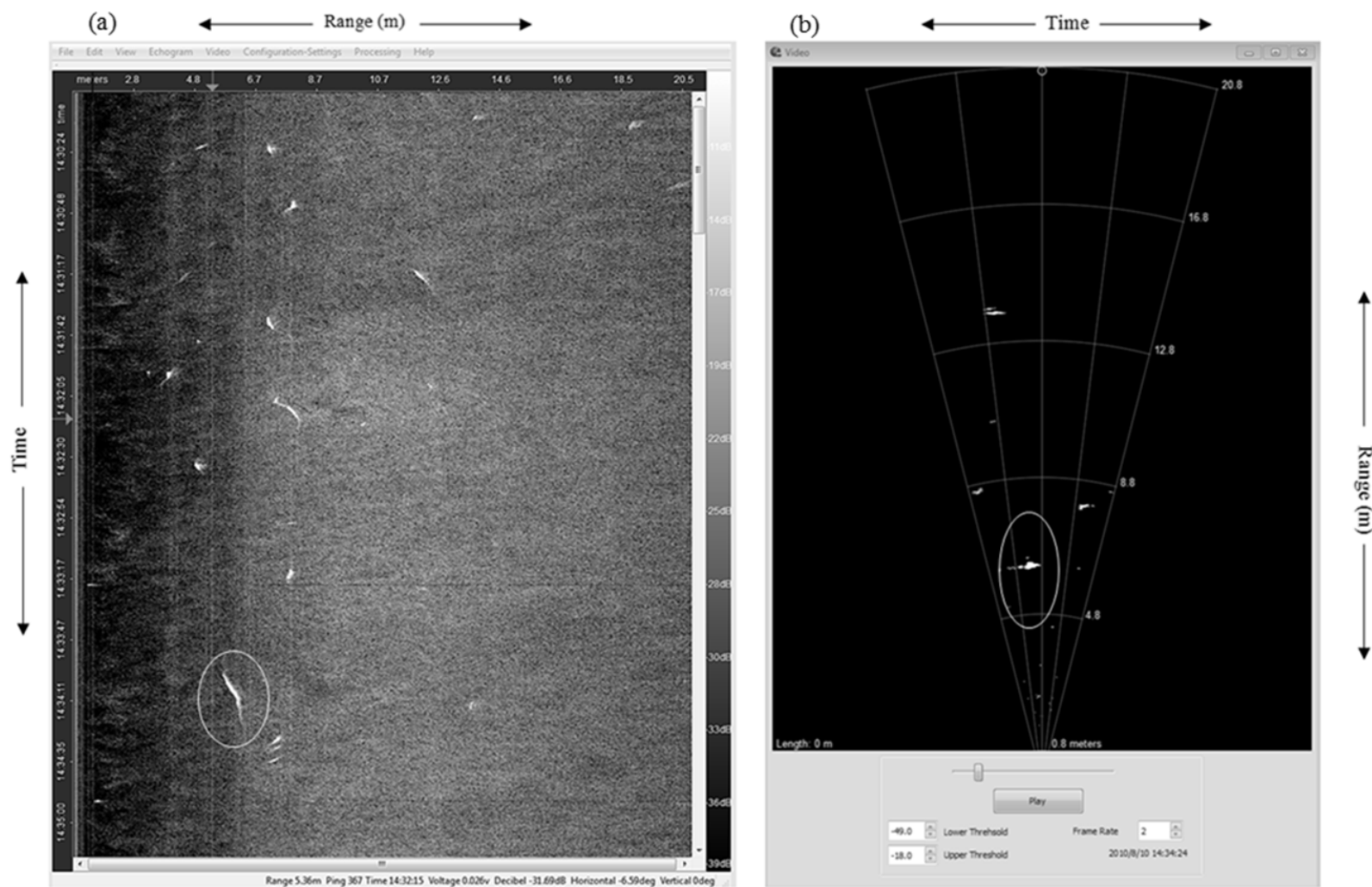
Figure 8.–Screenshots of echogram (a) and video (b) used to count and determine direction of travel from ARIS data files at the Eagle sonar project on the Yukon River, 2016.

Note: Ellipse encompasses typical upstream migrating salmon.
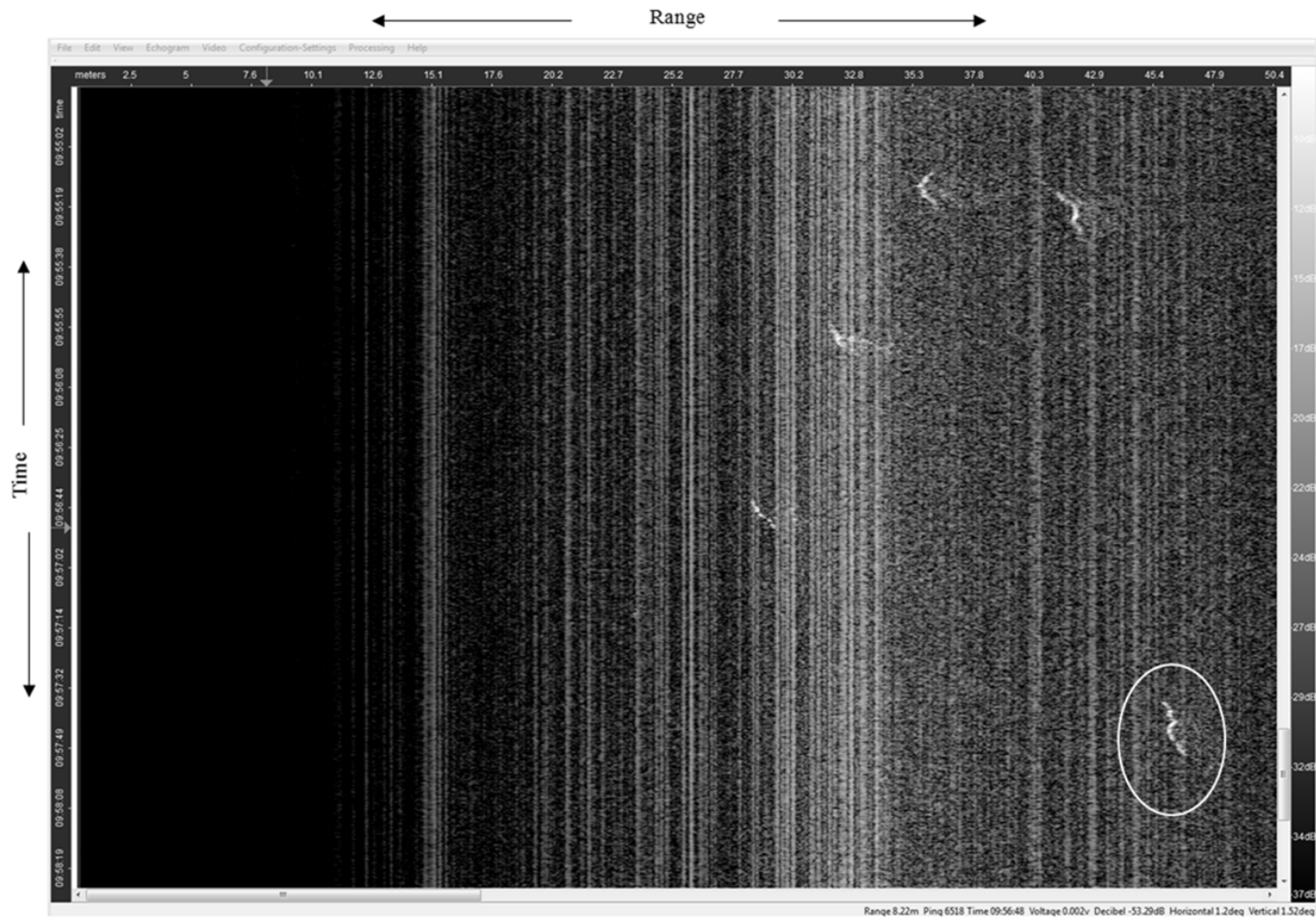
Figure 9.–Screenshot of echogram used to count and determine direction of travel from split-beam sonar data files at the Eagle sonar project on the Yukon River, 2016.

Note: Ellipse encompasses typical upstream migrating salmon.
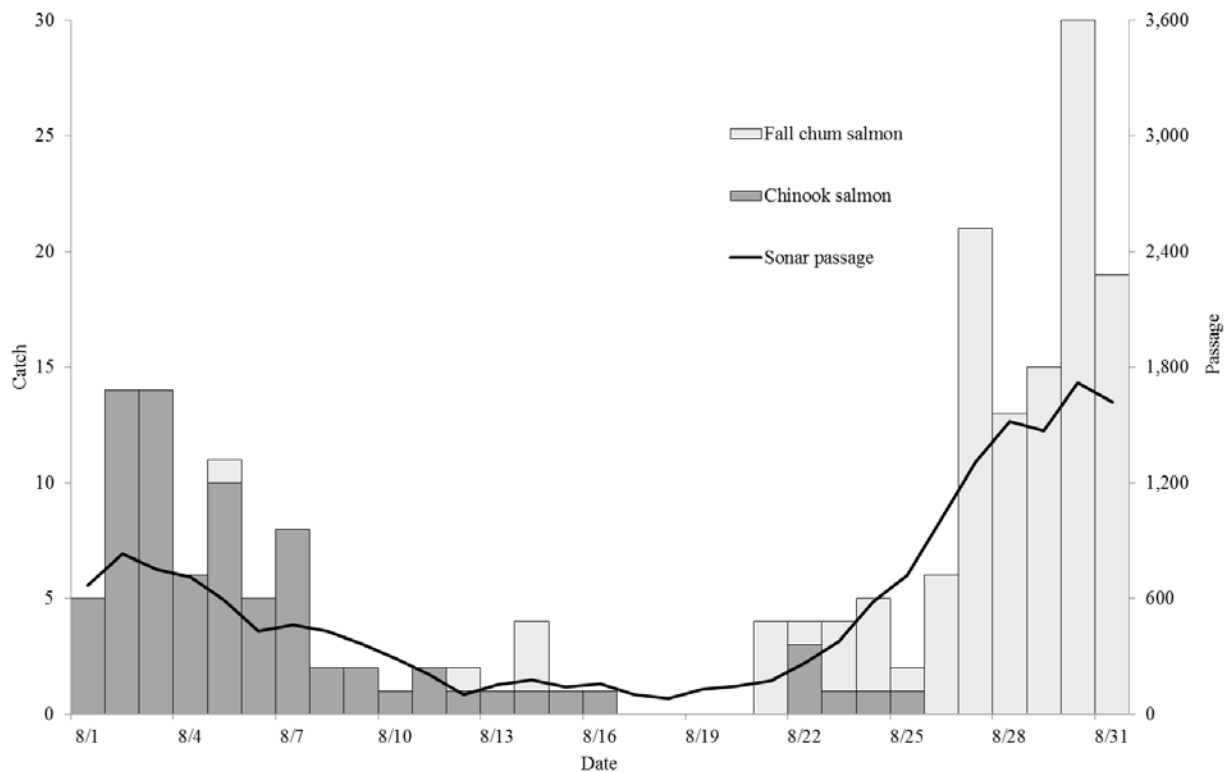
Figure 10.–Daily catch during species composition fishing and sonar passage estimates at the Eagle sonar project, on the Yukon River, 2016.
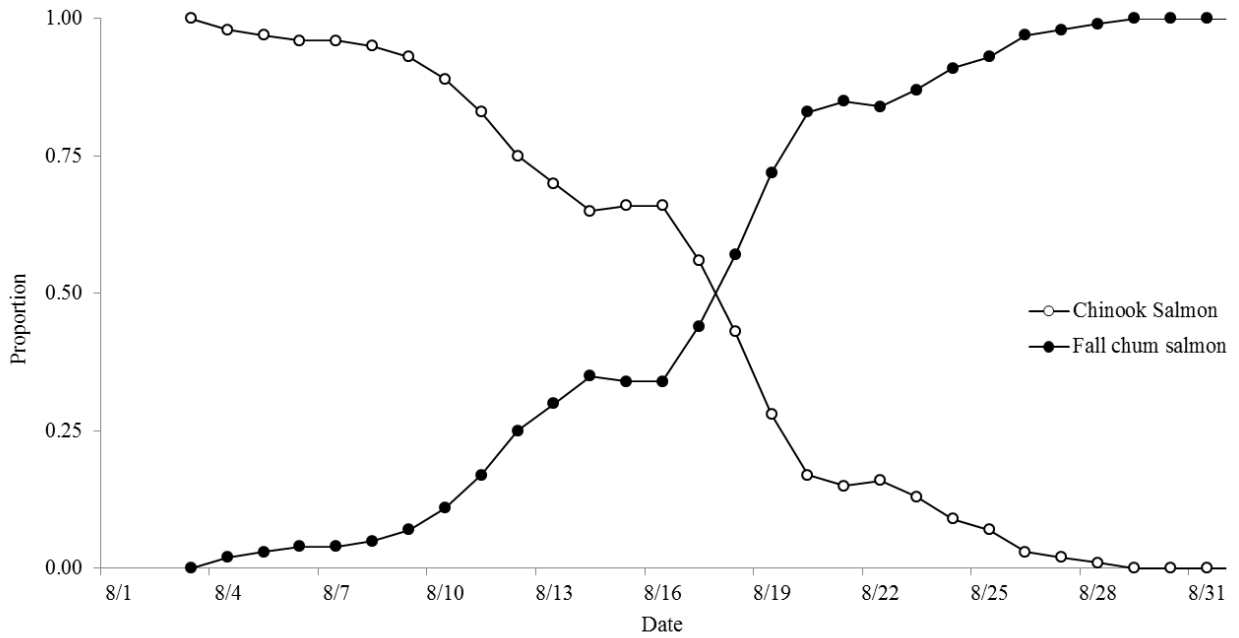
Figure 11.–Proportion of catch based on smoothed Chinook and fall chum salmon species composition CPUE data at the Eagle sonar project, on the Yukon River, 2016.

Note: Species changeover date (August 18) determined at the point the curves intersect.
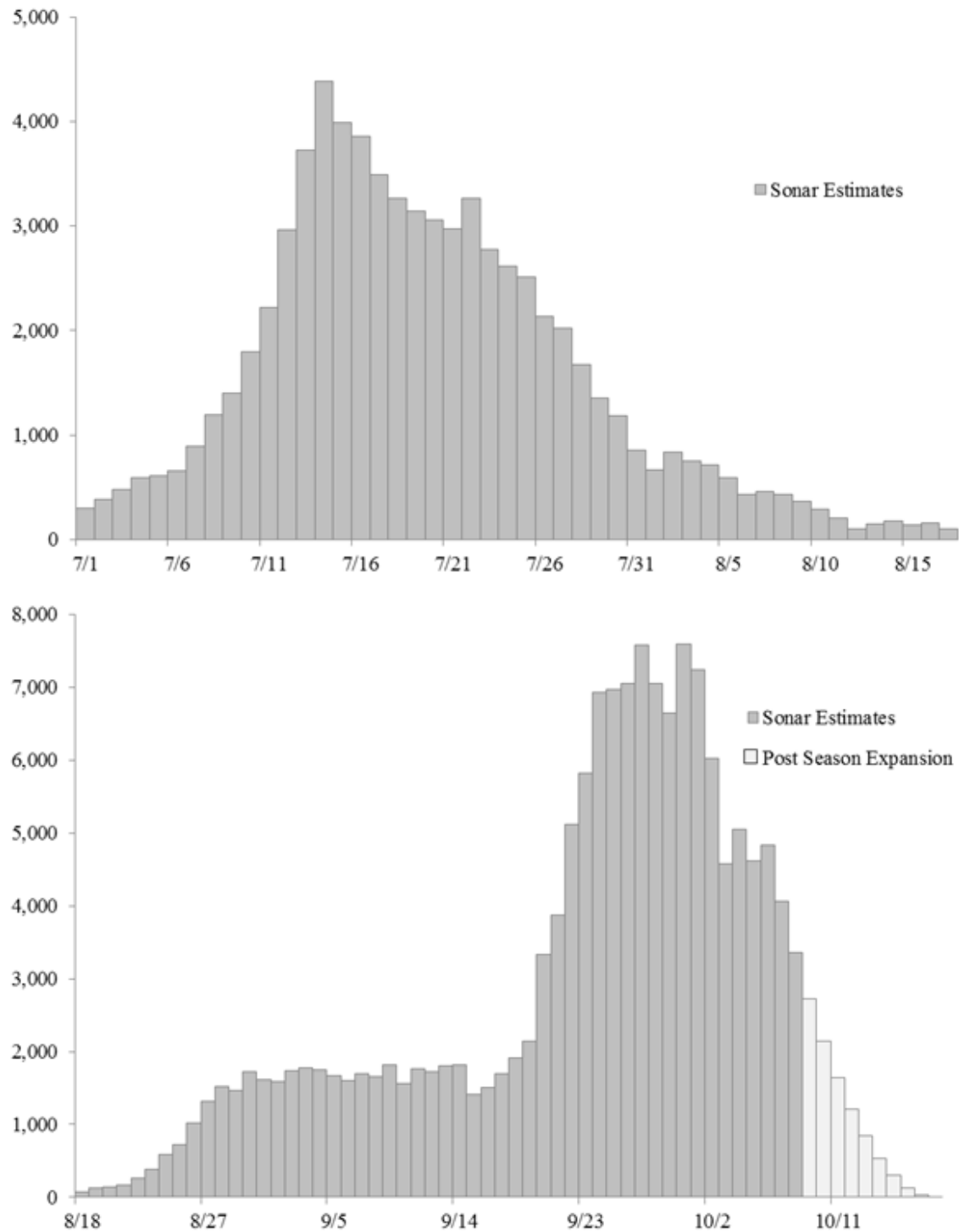
Figure 12.–Daily sonar estimates for Chinook salmon, July 1 through August 17, 2016 (top); daily sonar estimates, and postseason fall chum salmon expansion estimates for fall chum salmon, August 18 through October 18 (bottom).
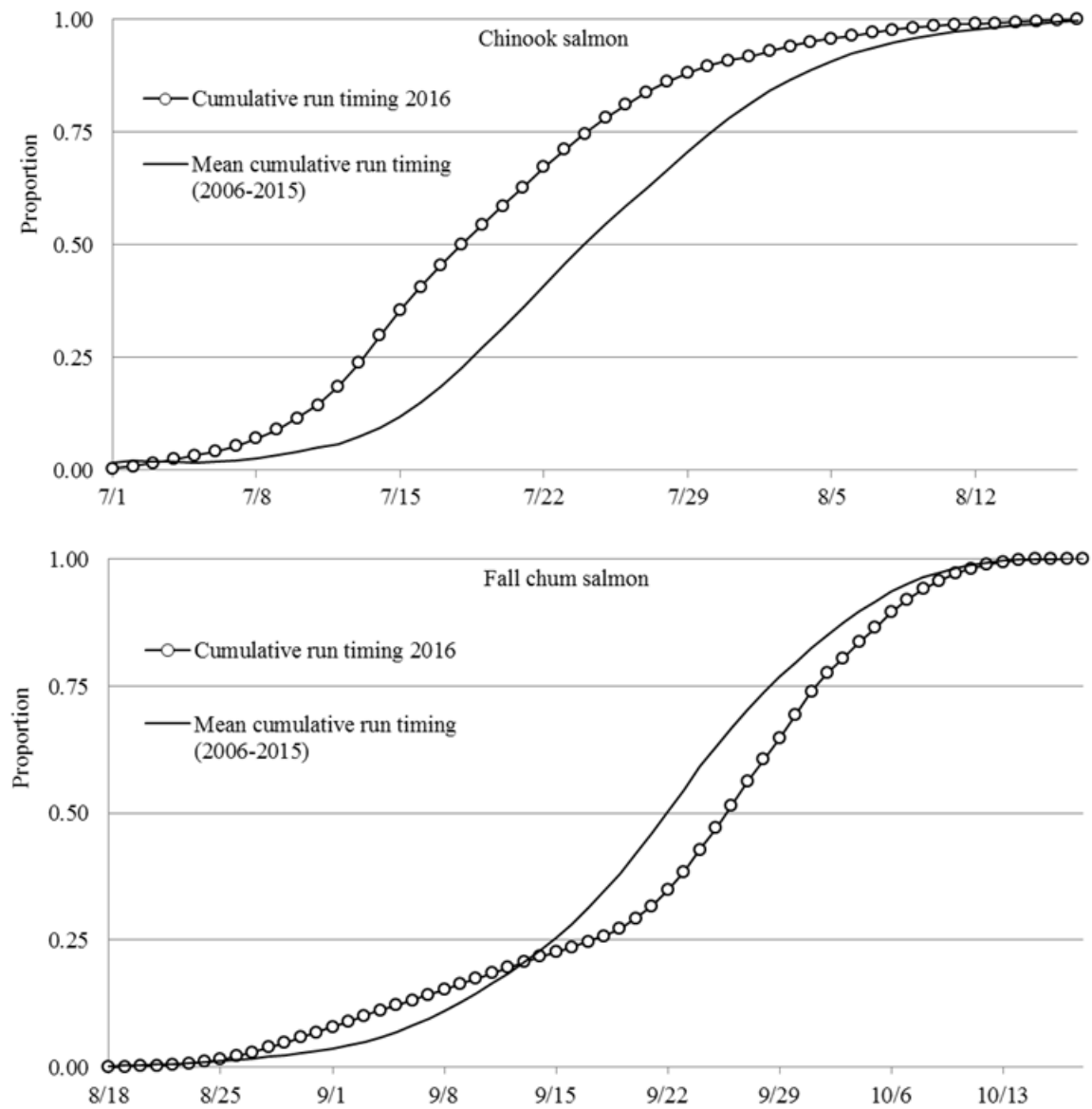
Figure 13.–2016 Chinook (top) and fall chum salmon (bottom) daily cumulative passage timing, compared to the 2005–2015 mean passage timing at the Eagle sonar project, on the Yukon River.

Note: Fall chum salmon cumulative passage timing includes postseason expansion estimates.
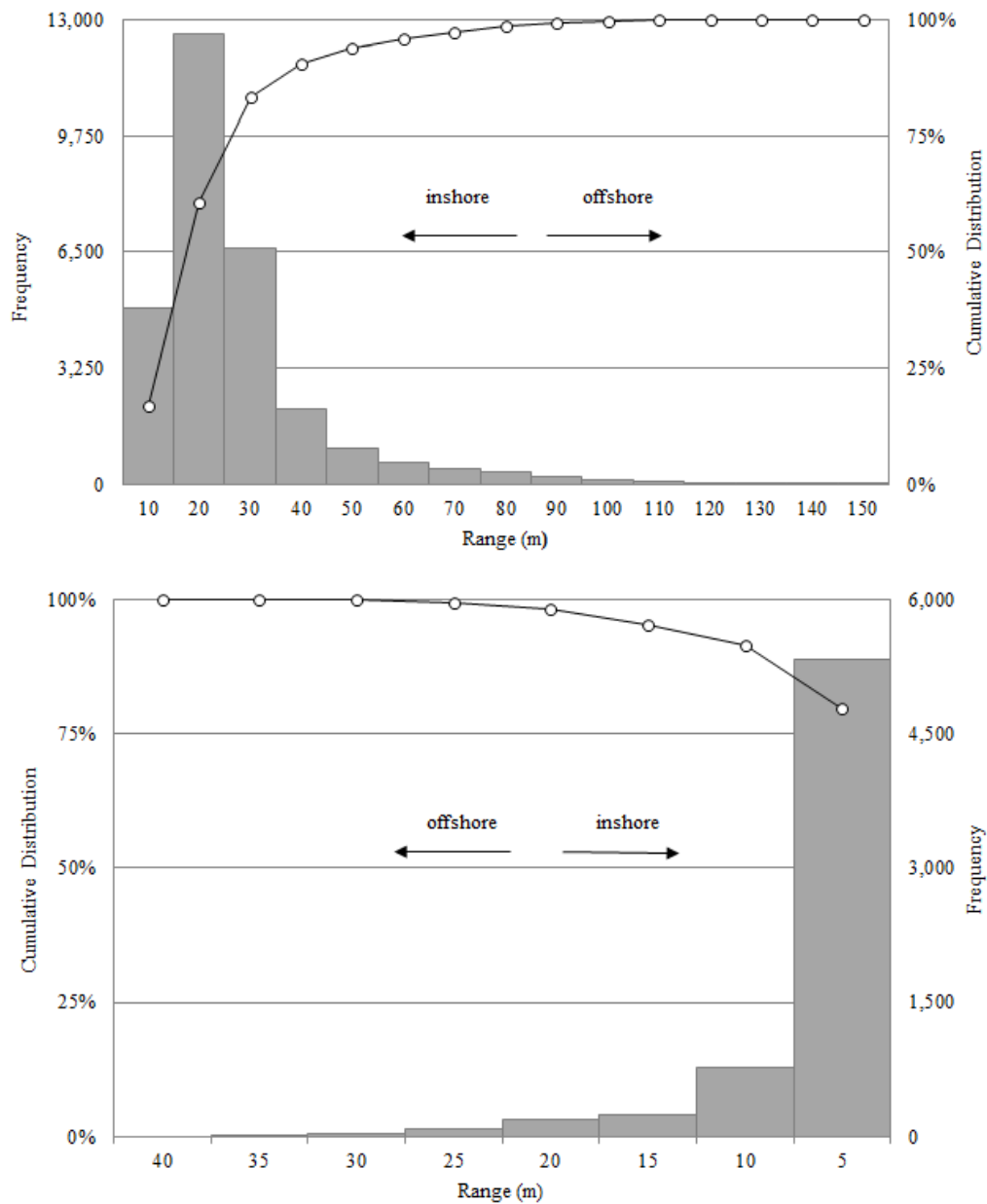
Figure 14.–Left bank (top) and right bank (bottom) horizontal distribution of upstream migrating Chinook salmon in the Yukon River at Eagle sonar project site, June 30 through August 17, 2016.
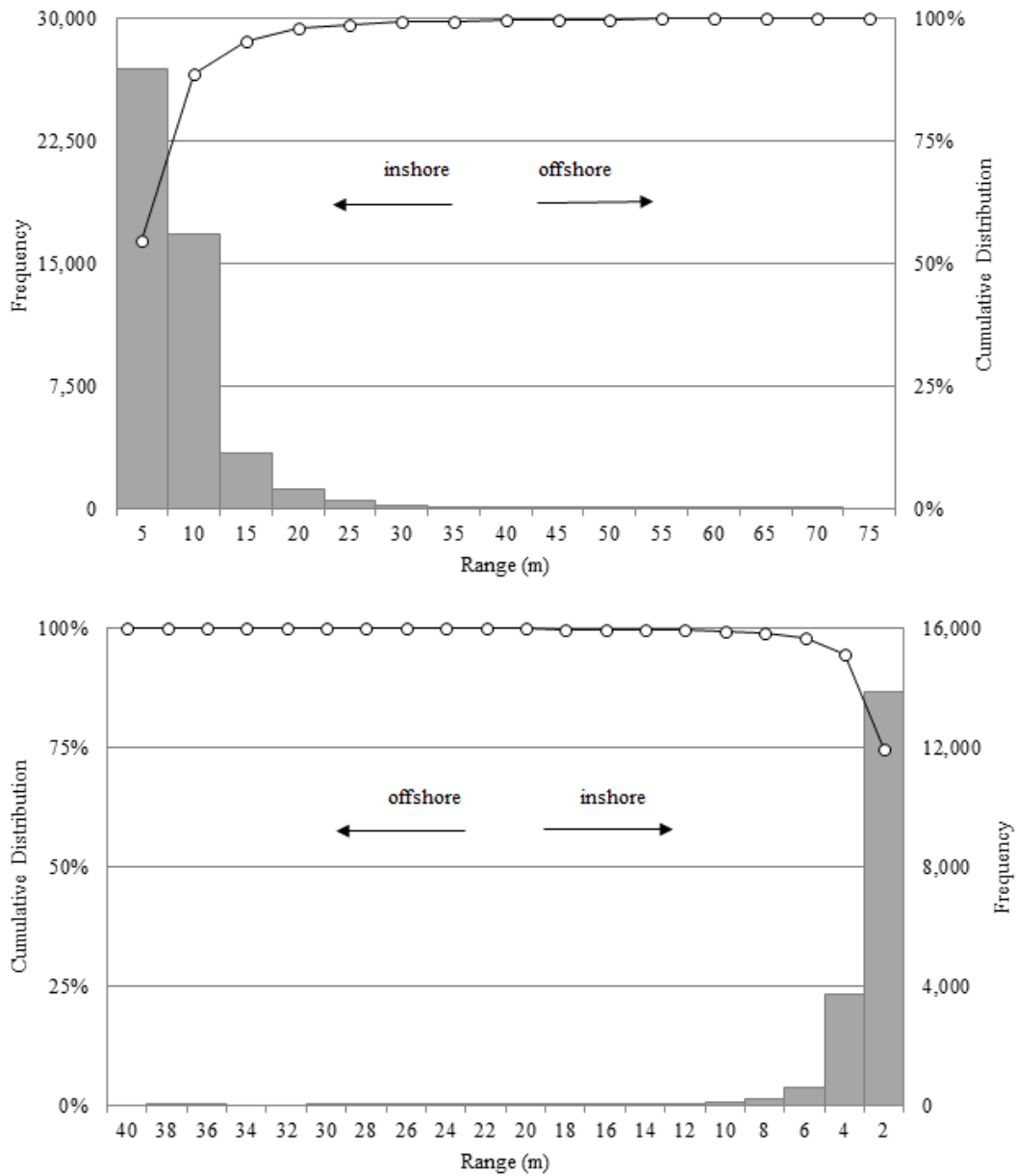
Figure 15.–Left bank (top) and right bank (bottom) horizontal distribution of upstream migrating fall chum salmon in the Yukon River at Eagle sonar project site, August 18 through October 6, 2016.
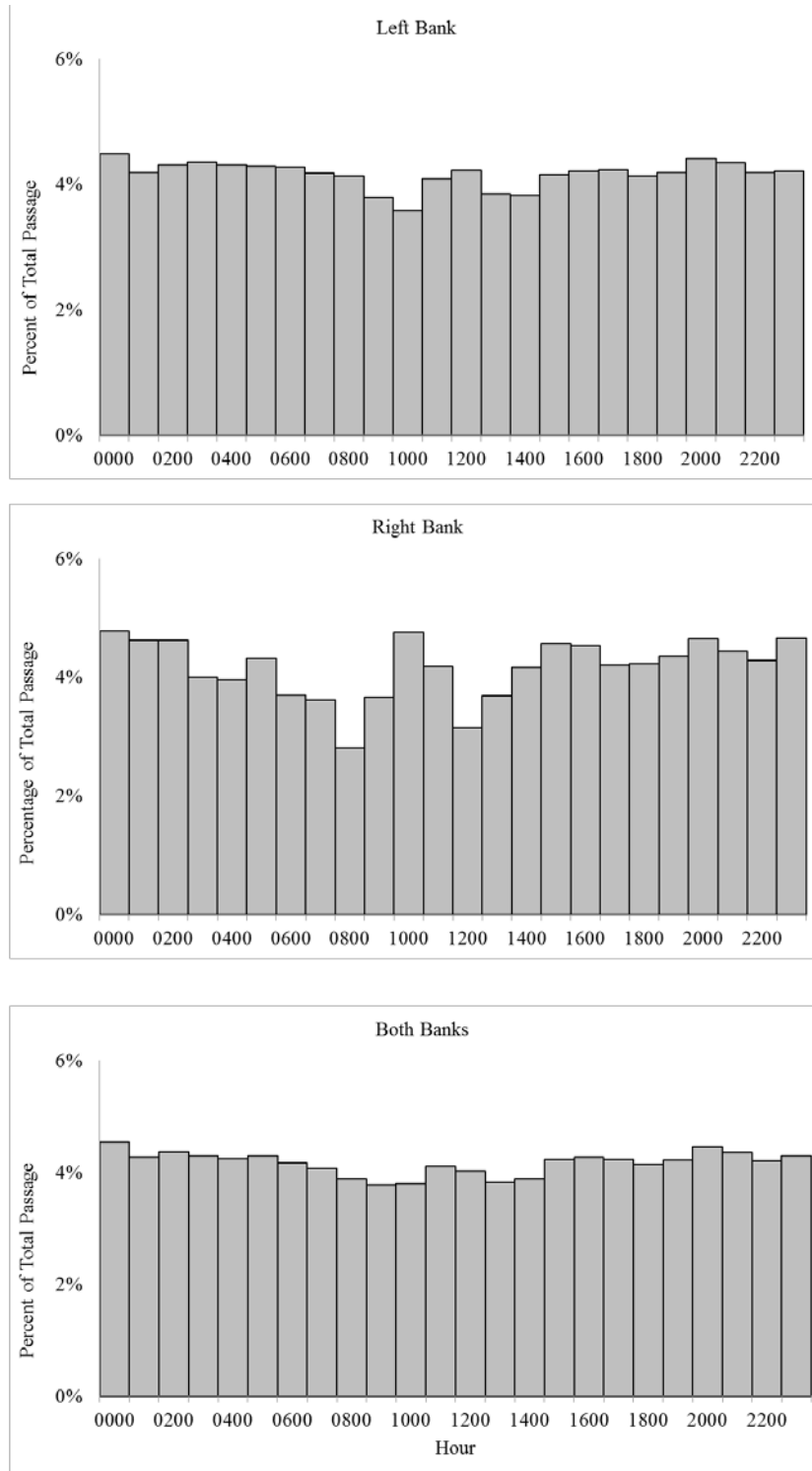
Figure 16.–Percentage of total Chinook salmon passage, by hour, observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from July 1 through August 17, 2016.
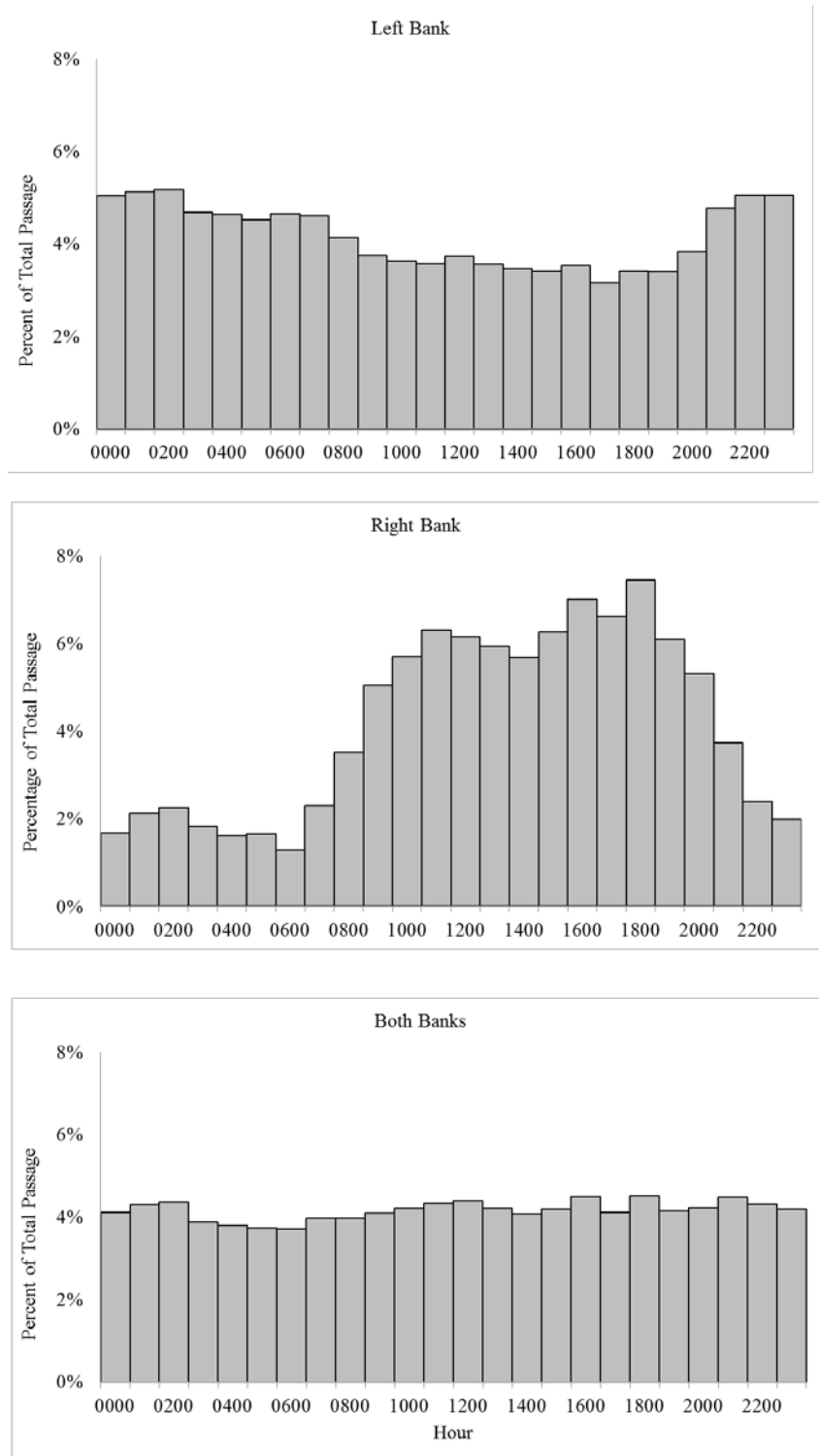
Figure 17.–Percentage of total fall chum salmon passage, by hour, observed on the left bank (top), right bank (middle), and both banks combined (bottom) of the Yukon River at the Eagle sonar project site from August 18 through October 6, 2016.
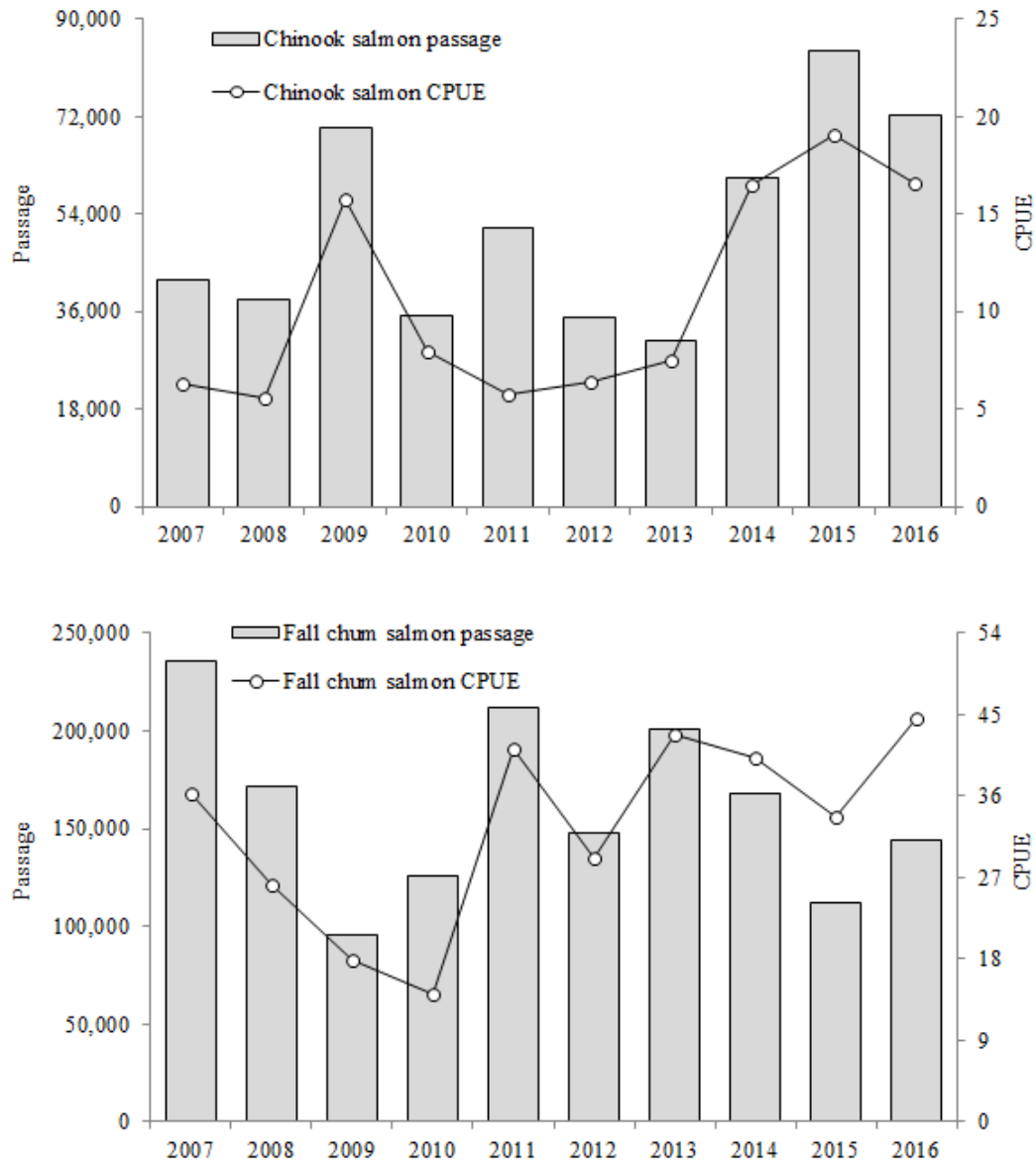
Figure 18.–Chinook (top) and fall chum salmon (bottom) passage and total cumulative catch per unit effort (CPUE) by year at the Eagle sonar project site, on the Yukon River, 2016.

Note: Because test fishing sites on the right bank have changed several times throughout the years, CPUE calculations are derived from the left bank fishery only. Prior to 2013, to avoid mortalities, there were occasions that fish were released without sampling, therefore for these years CPUE only represents fish sampled.
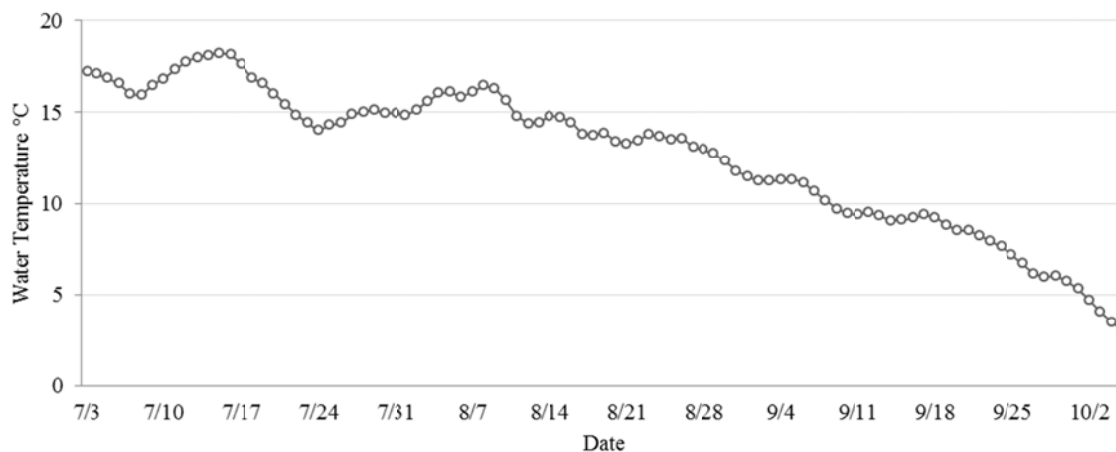
Figure 19.–Median daily water temperatures recorded on the left bank at the Eagle sonar project on the Yukon River, 2016.
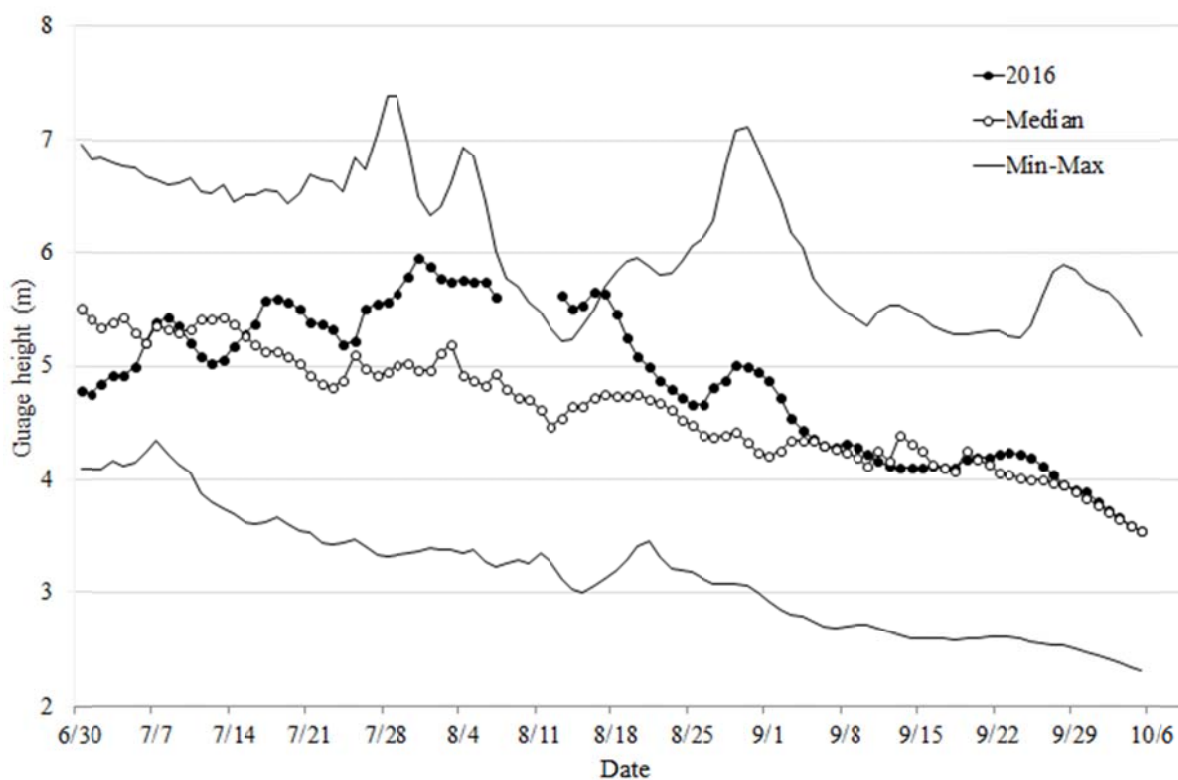
Figure 20.–Yukon River daily water level during the 2016 season at the Eagle water gage compared to minimum, maximum, and median gage height 1995 to 2015.

Source: United States Geological Survey.

Note: USGS gage out of service from August 8 to August 12, 2016.

APPENDIX A: SPECIES COMPOSITION TEST FISHERY CATCH, CPUE, AND SMOOTHED DATA BY DAY AND SALMON SPECIES

Appendix A1.–Species composition test fishery catch, CPUE, and smoothed data by day and salmon species at the Eagle sonar project, on the Yukon River, 2016.

	Chinook salmon						Fall chum salmon				
Date	Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed		Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
08/01	17.23	2	0.12	5	0.28		16.86	0	0.00	0	-0.02
08/02	17.70	12	0.68	5	0.28		16.49	0	0.00	0	-0.01
08/03	17.93	14	0.78	5	0.27		16.47	0	0.00	0	0.00
08/04	16.29	0	0.00	5	0.26		16.80	0	0.00	0	0.00
08/05	17.82	5	0.28	4	0.25		16.91	1	0.06	0	0.01
08/06	17.40	5	0.29	4	0.23		16.21	0	0.00	0	0.01
08/07	16.31	2	0.12	4	0.21		17.97	0	0.00	0	0.01
08/08	16.80	2	0.12	3	0.18		16.26	0	0.00	0	0.01
08/09	16.66	2	0.12	3	0.15		17.35	0	0.00	0	0.01
08/10	16.32	0	0.00	2	0.12		17.17	0	0.00	0	0.02
08/11	18.15	2	0.11	2	0.10		17.45	0	0.00	0	0.02
08/12	18.20	1	0.06	1	0.08		17.36	1	0.06	0	0.03
08/13	16.79	0	0.00	1	0.06		17.15	0	0.00	0	0.03
08/14	17.16	1	0.06	1	0.06		16.89	2	0.12	1	0.03
08/15	17.08	2	0.12	1	0.05		16.95	0	0.00	0	0.03
08/16	16.55	1	0.06	1	0.04		16.60	0	0.00	0	0.02
08/17	16.14	0	0.00	0	0.03		16.47	0	0.00	0	0.02
08/18	16.00	0	0.00	0	0.02		16.30	0	0.00	0	0.03
08/19	16.15	0	0.00	0	0.02		16.68	0	0.00	1	0.04
08/20	16.21	0	0.00	0	0.01		16.15	0	0.00	1	0.07
08/21	16.58	0	0.00	0	0.02		16.61	3	0.18	2	0.10
08/22	16.99	1	0.06	0	0.03		16.80	1	0.06	2	0.14
08/23	16.90	1	0.06	0	0.03		13.84	3	0.22	3	0.19
08/24	16.34	0	0.00	0	0.02		16.47	4	0.24	4	0.25
08/25	18.61	1	0.05	0	0.02		16.34	1	0.06	5	0.31
08/26	16.43	0	0.00	0	0.02		17.01	4	0.24	7	0.42
08/27	17.26	0	0.00	0	0.01		17.32	13	0.75	9	0.55
08/28	16.61	0	0.00	0	0.00		16.91	8	0.47	12	0.66
08/29	16.42	0	0.00	0	0.00		17.17	13	0.76	14	0.79
08/30	17.39	0	0.00	0	0.00		18.83	27	1.43	16	0.92
08/31	17.30	0	0.00	0	0.00		17.55	15	0.86	17	0.96

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Date	Chinook salmon					Fall chum salmon				
	Large mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed	Small mesh fathom hours	Catch	CPUE	Catch smoothed	CPUE smoothed
09/01	17.31	0	0.00	0	0.00	18.21	20	1.10	17	0.98
09/02	17.71	0	0.00	0	0.00	17.33	18	1.04	17	0.95
09/03	17.25	0	0.00	0	0.00	17.48	20	1.14	16	0.89
09/04	17.18	0	0.00	0	0.00	17.25	12	0.70	14	0.81
09/05	17.23	0	0.00	0	0.00	17.61	10	0.57	13	0.76
09/06	16.48	0	0.00	0	0.00	17.12	7	0.41	13	0.72
09/07	17.57	0	0.00	0	0.00	17.87	8	0.45	12	0.71
09/08	16.63	0	0.00	0	0.00	16.96	17	1.00	12	0.72
09/09	16.48	0	0.00	0	0.00	23.45	17	0.73	12	0.74
09/10	16.82	0	0.00	0	0.00	15.72	9	0.57	12	0.75
09/11	13.44	0	0.00	0	0.00	13.41	9	0.67	12	0.77
09/12	12.81	0	0.00	0	0.00	14.10	17	1.21	13	0.80
09/13	12.88	0	0.00	0	0.00	14.75	17	1.15	13	0.82
09/14	14.00	0	0.00	0	0.00	14.18	6	0.42	14	0.84
09/15	14.03	0	0.00	0	0.00	14.52	8	0.55	14	0.88
09/16	14.88	0	0.00	0	0.00	15.06	15	1.00	16	0.95
09/17	14.00	0	0.00	0	0.00	15.23	14	0.92	17	1.03
09/18	16.27	0	0.00	0	0.00	16.41	17	1.04	18	1.13
09/19	16.52	0	0.00	0	0.00	16.14	10	0.62	20	1.30
09/20	17.19	0	0.00	0	0.00	19.33	27	1.40	22	1.51
09/21	17.34	0	0.00	0	0.00	18.08	32	1.77	24	1.69
09/22	15.36	0	0.00	0	0.00	15.83	28	1.77	26	1.87
09/23	14.16	0	0.00	0	0.00	8.95	30	3.35	27	2.01
09/24	16.41	0	0.00	0	0.00	15.74	39	2.48	29	2.10
09/25	3.21	0	0.00	0	0.00	7.06	14	1.98	29	2.15
09/26	15.38	0	0.00	0	0.00	15.43	42	2.72	30	2.20
09/27	13.34	0	0.00	0	0.00	14.47	32	2.21	31	2.25
09/28	15.06	0	0.00	0	0.00	15.70	34	2.17	32	2.31
09/29	14.34	0	0.00	0	0.00	13.31	20	1.50	33	2.38
09/30	14.85	0	0.00	0	0.00	13.97	36	2.58	34	2.44

53

APPENDIX B: CLIMATE AND HYDROLOGIC OBSERVATIONS

Appendix B1.–Climate and hydrologic observations recorded daily at 1800 hours, at the Eagle sonar project site on the Yukon River, 2016.

	Precipitation	Wind		Sky	Temperature (°C)	
Date	(code)[a]	Direction	Velocity (kph)	(code)[b]	Air	Water[c]
07/02	B	NW	2.7	B	17.7	16.5
07/03	B	NW	6.8	B	18.9	17.0
07/04	B	E	6.4	B	19.4	17.0
07/05	B	E	2.1	B	18.8	17.0
07/06	B	NW	3.4	B	20.8	17.0
07/07	B	NW	3.7	B	18.5	15.0
07/08	B	SE	7.3	B	18.4	17.0
07/09	A	NNW	3.5	B	21.0	16.0
07/10	A	NNW	3.5	S	21.0	17.0
07/11	B	WNW	2.9	B	20.0	17.0
07/12	A	NNW	8.5	S	25.0	19.0
07/13	A	WNW	5.0	S	28.0	19.0
07/14	B	NNE	6.8	B	26.0	18.5
07/15	A	W	4.5	B	24.0	18.0
07/16	B	SE	2.7	B	18.9	17.5
07/17	B	SE	6.3	O	17.3	17.0
07/18	B	SE	34	O	16.1	16.0
07/19	B	NW	4.2	B	22.8	16.5
07/20	B	NW	6.8	S	18.2	15.0
07/21	B	SE	5.5	O	14.4	15.0
07/22	B	NW	6.6	B	18.8	15.0
07/23	B	N	12.2	B	16.8	14.5
07/24	A	ND	0.0	B	15.0	14.0
07/25	A	ND	0.0	S	19.0	15.0
07/26	B	ND	0.0	B	14.0	14.0
07/27	A	SW	9.7	S	24.0	15.0
07/28	B	ND	0.0	O	17.0	15.0
07/29	B	NE	3.2	O	15.0	15.0
07/30	B	ND	0.0	O	17.0	15.0
07/31	B	W	1.5	B	18.5	15.0
08/01	B	SE	6.8	B	22.2	15.0
08/02	B	N	2.1	S	22.7	16.5
08/03	B	NW	8.9	B	17.1	15.0
08/04	B	NW	6.3	B	20.2	16.0
08/05	B	SE	6.4	S	18.2	15.5
08/06	B	S	4.0	B	20.4	15.5
08/07	B	S	7.4	A	23.8	16.0
08/08	B	N	9.3	B	17.3	15.5
08/09	C	ND	0.0	O	15.2	15.0
08/10	B	NW	3.5	B	19.4	14.5
08/11	B	S	1.6	B	22.3	14.5

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Date	Precipitation (code)[a]	Wind Direction	Velocity (kph)	Sky (code)[b]	Temperature (°C) Air	Water[c]
08/12	B	SW	1.6	B	20.2	14.5
08/13	B	SE	4.0	B	21.9	14.5
08/14	B	NW	2.3	B	18.4	14.5
08/15	B	S	4.2	O	15.4	14.0
08/16	A	ND	0.0	B	18.0	14.0
08/17	A	ND	0.0	S	17.1	14.0
08/18	A	ND	0.0	B	16.7	13.0
08/19	A	ND	0.0	S	15.0	14.0
08/20	B	ND	0.0	O	16.0	13.0
08/21	A	NEE	11.9	B	17.0	12.0
08/22	A	SEE	6.4	O	17.0	12.0
08/23	A	SE	18.2	B	19.0	13.0
08/24	A	SSE	3.7	S	20.0	14.0
08/25	C	NWW	1.3	O	13.0	12.0
08/26	A	W	5.0	S	18.0	14.0
08/27	B	NEE	4.4	O	13.0	13.0
08/28	A	E	8.1	C	13.0	12.0
08/29	A	NW	8.1	S	14.0	13.0
08/30	A	W	6.4	C	14.0	13.0
08/31	A	ND	0.0	B	13.0	12.0
09/01	A	NW	4.8	B	13.0	11.0
09/02	A	NW	4.8	B	11.0	11.0
09/03	A	ND	0.0	C	12.0	11.0
09/04	A	W	1.6	C	12.0	11.0
09/05	B	ND	0.0	O	14.0	11.0
09/06	B	W	4.8	O	8.0	10.5
09/07	A	NW	6.4	S	8.0	10.5
09/08	A	W	3.2	C	6.0	10.5
09/09	A	NWW	4.8	C	8.0	10.0
09/10	A	ND	0.0	C	6.0	10.0
09/11	A	SE	4.8	O	13.0	9.5
09/12	A	S	8.1	B	12.0	9.5
09/13	B	NEE	4.8	O	10.0	9.0
09/14	B	NNW	4.8	O	10.0	9.0
09/15	A	ND	0.0	O	13.0	9.0
09/16	B	W	3.2	O	9.0	8.5
09/17	B	N	9.7	O	9.0	8.5
09/18	B	ND	0.0	B	10.0	8.5
09/19	A	ND	0.0	B	10.0	8.0
09/20	A	SE	8.1	B	8.0	8.0
09/21	A	SE	12.9	O	13.0	8.0

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Appendix B1.–Page 3 of 3.

Date	Precipitation (code)[a]	Wind		Sky (code)[b]	Temperature (°C)	
		Direction	Velocity (kph)		Air	Water[c]
09/22	B	SE	8.1	O	10.0	8.0
09/23	A	S	3.2	S	10.0	7.5
09/24	A	S	3.2	S	8.0	7.0
09/25	A	N	11.3	B	6.0	6.5
09/26	A	NW	4.8	C	3.0	6.5
09/27	A	ND	0.0	O	3.0	6.0
09/28	A	ND	0.0	C	5.0	5.5
09/29	A	ND	0.0	B	2.0	5.5
09/30	A	N	1.6	O	6.0	5.0
10/01	A	ND	0.0	C	2.0	5.0
10/02	A	NE	4.2	C	3.0	4.0
10/03	A	ND	0.0	S	-2.0	3.0
10/04	A	ND	0.0	C	-1.0	3.0
10/05	A	ND	0.0	C	-1.0	2.0

[a] Precipitation code for the preceding 24 hour period: A = none; B = intermittent rain; C = continuous rain; D = snow and rain mixed; E = light snowfall; F = continuous snowfall; G = thunderstorm with or without precipitation.

[b] Instantaneous cloud cover code: C = clear, cloud cover <10% of sky; S = cloud cover <60% of sky; B = cloud cover 60–90% of sky; O = overcast (100%); F = fog, thick haze or smoke.

[c] Water temperature collected approximately 30 cm below surface with Hobo U22 Data logger.